A COMPLETE TEXT BOOK ON
COAL

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1. Coal — Combustion

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COAL

ITS ECONOMICAL AND SMOKELESS COMBUSTION

BY

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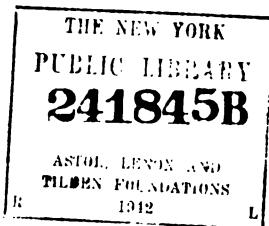
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PREFACE

This work was called forth by the lack of a thorough, comprehensive textbook on coal that would explain in clear, simple language just what must be known about the characteristics of the numerous varieties in order that coal may be purchased intelligently and burned economically and smokelessly.

Fully ninety-eight per cent. of industrial plants use coal as a prime source of power, yet, owing to lack of knowledge of this subject, they seldom get the kind of coal best suited to their equipments. A large majority burn coal that can be burned neither economically nor smokelessly in their plants. Instances are on record where selecting the coal best suited to a plant reduced the coal bills fully twenty per cent; and it is safe to say that fully ten per cent can be saved in half the plants in operation simply by selecting the right coal for the furnace and draft.

In many cases plants have been forced to restrict their outputs or to increase their boiler capacity by an extra unit, when by simply selecting the right coal for their furnaces and by adjusting the draft to suit their conditions they would have gained the desired increase in capacity.

With a given equipment and the right kind of coal, the capacity, economy, and smokeless operation of a locomotive or a power plant depends on the right manipulation of the fires. In this work, that phase of the subject is treated in an exhaustive manner, so that a person of average intelligence by studying the text can determine what is the best coal to purchase for his particular plant; what equipment is best suited to burn a particular kind of coal; what method of firing is best adapted to the coal and furnace; and what the best method of procedure is for the prevention of smoke. This applies

with equal force to locomotive service, marine service, and stationary power service, and applying the information herein contained will effect wonders in economy, efficiency, and smokelessness of operation.

To cope successfully with the smoke problem requires a special knowledge of the smoke-producing constituents of coal and of the types of furnaces best suited to the burning of coal smokelessly. All this is explained in detail and well illustrated, and, besides, the laws governing the production and prevention of smoke are thoroughly interpreted.

The formation of clinker in a furnace not only is a source of great trouble to the fireman, but also is a cause of steam failures, with consequent delays and shutdowns. This subject received special consideration, particularly the cause and prevention of clinker, the methods of determining from the constituents of the ash whether an ash will clinker, and the best methods of handling clinkers once they have formed.

The scope of this book is so broad, and the subjects are treated in so comprehensive a manner, that it is hoped the book will be of special benefit to mechanical engineers, electrical engineers, heat engineers, smoke inspectors, fuel inspectors, purchasing agents, power-plant owners, power plant superintendents, superintendents of motive power, master mechanics, traveling engineers, traveling firemen, engineers, firemen, and in engineering class rooms.

SCRANTON, PA., Feb. 15, 1916.   J. F. COSGROVE.

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CHAPTER I

CLASSIFICATION OF COALS

OAL is the carboniferous remains of prehistoric vegetable matter. In America it is widely distributed throughout the United States, Canada, and Mexico, where it is found in various stages of carbonization. Wood fiber (cellulose) is the lowest group in the series, while the successive groups are known as peat, lignite, bituminous coal, semibituminous coal, semianthracite, anthracite, and graphite. In the lower groups, the coal is low in carbon and very high in oxygen. Each higher group is distinguished by an increase in carbon and a decrease in oxygen, as is shown in Table I. The hydrogen remains practically the same for all groups below the semibituminous, but decreases rapidly in the higher groups. Oxygen in coal is considered an impurity, because it has the same effect on the heat value of the coal as a like amount of ash; hence, the lower groups have a much lower heat value than the higher groups.

Each of the coal groups comprise a number of classes of coal that differ largely in physical characteristics rather than in chemical composition; consequently, it is hard to define each group accu-

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TABLE I.

Fuels Grouped According to Their Carbon and Oxygen Content.

Substance	Per Cent. Carbon	Per Cent. Oxygen	Per Cent. Hydrogen
Wood fiber (cellulose)......	52.65	42.10	5.25
Peat	59.57	34.47	5.96
Lignite	66.04	28.69	5.27
Bituminous coal...........	73.18	21.14	5.58
Semibituminous coal........	75.06	19.10	5.84
Semianthracite	89.29	6.66	5.05
Anthracite	91.58	4.46	3.56
Graphite	100.00		

rately. The anthracite, semianthracite, and semi-
bituminous groups are fairly easy to define, but the
term bituminous embraces such a wide variety of
coals that it is of but little value in defining limits.
The term lignite is even more loosely defined. In
fact, no method of accurately defining the various
classes of coals is generally accepted because of the
difficulty of adapting a scheme of classification that
will apply to lignites, as well as to bituminous coal
and to anthracite. Various schemes of classification
have been proposed from time to time, but none
have been entirely satisfactory. One classification,
Table II, is the Carbon-Hydrogen Ratio Classifica-
tion proposed by Mr. M. R. Campbell and based on
tests made by the U. S. Geological Survey and on
the results of numerous government ultimate analy-
sis of coals from all parts of the country.

It is claimed that carbon and hydrogen are
almost equally valuable fuel elements of coal; hence,
a classification to be satisfactory should take them
both into account.

TABLE II.

Coals Arranged According to Carbon and Hydrogen Content.

Name of Sample	Name of Bed or Field	Per Cent. Hydrogen	Per Cent. Carbon
Pennsylvania, No. 3..	Anthracite	3.39	90.73
Arkansas, No. 5.....	Spadra bed	4.36	90.11
West Virginia, No. 11	Pocahontas bed	4.58	89.95
Arkansas, No. 2.....	Huntington bed	4.65	90.18
Arkansas, No. 1.....	Huntington bed	4.66	88.16
West Virginia, No. 7.	New River field	4.67	87.95
Arkansas, No. 3.....	Huntington bed	4.68	87.89
West Virginia, No. 12	Pocahontas field	4.72	90.55
West Virginia, No. 10	Pocahontas field	4.83	90.63
West Virginia, No. 6.	New River field	4.99	88.72
West Virginia, No. 4.	Upper Freeport bed	5.35	86.26
West Virginia, No. 5.	Upper Freeport bed	5.38	85.97
West Virginia, No. 9.	Kanawha field	5.46	85.86
Alabama, No. 2......	Warrior field	5.54	80.10
Pennsylvania No. 4..	Connellsville field	5.54	87.10
West Virginia, No. 3.	Upper Freeport bed	5.54	85.95
Kentucky No. 4......	Western field	5.62	82.38
West Virginia, No. 8.	Kanawha field	5.62	85.86
West Virginia, No. 1.	Pittsburg bed	5.67	84.45
Illinois, No. 3.......	Marion County	5.68	77.67
Kentucky, No. 1......	Eastern field	5.68	83.03
Indian Territory, No. 3	McAlester bed	5.70	80.17
Alabama, No. 1......	Warrior field	5.73	83.29
Indian Territory, No. 2	Hartshorne bed	5.74	82.07
West Virginia, No. 2.	Pittsburg bed	5.75	84.01
Kansas, No. 5.......	Weir-Pittsburg bed	5.81	84.45
Indian Territory, No. 1	Henryetta bed	5.86	79.69
Indian Territory, No. 4	McAlester bed	5.86	76.55
Iowa, No. 1.........	Wapello County	5.88	78.96
Texas, No. 2........	Brown Lignite, Wood Co..	5.90	64.05
Kansas, No. 1.......	Weir-Pittsburg bed	5.95	82.68
Illinois, No. 6.......	Montgomery County	6.04	74.86
Montana, No. 1......	Red Lodge	6.04	69.41
North Dakota, No. 2	Brown Lignite, Williston f.	6.05	59.54
Kansas No. 2.......	Weir-Pittsburg bed.......	6.06	83.81

TABLE II—Continued.

Name of Sample	Name of Bed or Field	Per Cent. Hydrogen	Per Cent. Carbon
North Dakota, No. 1.	Brown Lignite, Lehigh fd.	6.08	61.43
Kentucky, No. 3.....	Western field............	6.12	77.52
Kentucky, No. 2.....	Western field............	6.13	77.85
Illinois, No. 4........	Belleville field...........	6.14	71.18
Wyoming, No. 2.....	Cambria field............	6.17	75.15
Colorado, No. 1......	Black Lignite, Bolder field	6.18	65.71
Illinois, No. 1........	Belleville field...........	6.21	75.79
New Mexico, No. 1...	Black Lignite, Gallup field.	6.21	69.74
Indiana, No. 1.......	Sullivan County.........	6.22	74.39
Iowa, No. 2.........	Marion County	6.22	77.59
Indiana, No. 2......	Warrick County	6.24	76.89
Missouri, No. 1......	Rich Hill field...........	6.26	80.99
Iowa, No. 4.........	Appanoose County.......	6.32	72.86
Iowa, No. 3.........	Polk County............	6.35	78.08
New Mexico, No. 2...	Black Lignite, Gallup field.	6.35	71.35
Kansas, No. 4.......	Atchison field............	6.37	82.27
Missouri, No. 2......	Bevier field..............	6.41	72.68
Iowa, No. 5.........	Lucas County...........	6.44	72.14
Wyoming, No. 1.....	Black Lignite, Sheridan fd.	6.44	61.76
Missouri, No. 4......	Morgan County..........	6.46	81.22
Texas, No. 1........	Brown Lignite, Houston Co.	6.62	61.90

From Table II it will be noted that as the percentage of hydrogen increases the percentage of carbon decreases; consequently, either subtraction or division must be used to express a relation between them. In the Carbon-Hydrogen Ratio Classification, division is employed, the per cent. of carbon being divided by the per cent. of hydrogen to give the ratio.

TABLE III.

Classification of Coals According to Carbon-Hydrogen Ratios.

Name of Sample	Name of Bed or District	Carbon-Hydrogen Ratio
	Groups A, B and C	
Pennsylvania, No. 3..	Anthracite	26.7
	Groups D and E	
Arkansas, No. 5......	Spadra bed...............	20.7
	Group F	
West Virginia, No. 11	Pocahantos field...........	19.6
Arkansas, No. 2......	Huntington bed.............	19.3
West Virginia, No. 12	Pocahontas field...........	19.2
Arkansas No. 1......	Huntington bed.............	18.9
Arkansas, No. 3......	Huntington bed.............	18.8
West Virginia, No. 7.	New River field............	18.8
West Virginia, No. 10	Pocahontas field...........	18.7
West Virginia, No. 6.	New River field............	17.8
	Group G	
West Virginia, No. 4.	Upper Freeport bed........	16.1
West Virginia, No. 5.	Upper Freeport bed........	15.9
Pennsylvania, No. 4..	Connellsville field..........	15.7
West Virginia, No. 9.	Kanawha field.............	15.7
West Virginia, No. 3.	Upper Freeport bed........	15.5
West Virginia, No. 8.	Kanawha field.............	15.3
West Virginia, No. 1.	Pittsburg bed.............	14.7
Kentucky, No. 1......	Eastern field..............	14.6
Kentucky, No. 4......	Western field..............	14.6
Alabama, No. 1......	Warrior field..............	14.5
Alabama, No. 2......	Warrior field..............	14.5
Kansas, No. 5........	Weir-Pittsburg bed.........	14.5
West Virginia, No. 2.	Pittsburg bed.............	14.4
	Group H	
Indian Territory, No.2	Hartshorne bed............	14.3
Indian Territory, No.3	McAlester bed.............	14.1
Kansas, No. 1........	Weir-Pittsburg bed.........	13.9
Kansas, No. 2........	Weir-Pittsburg bed.........	13.8
Illinois, No. 3........	Marion County.............	13.7
Indian Territory, No.1	Henryetta bed.............	13.6

TABLE III—Continued.

Name of Sample	Name of Bed or District	Carbon-Hydrogen Ratio
Iowa, No. 1..........	Wapello County............	13.4
Indian Territory, No.4	McAlester bed..............	13.1
Kansas, No. 4........	Atchison field..............	12.9
Missouri, No. 1......	Rich Hill field..............	12.9
Kentucky, No. 2......	Western field..............	12.7
Kentucky, No. 3......	Western field..............	12.6
Missouri, No. 4.......	Morgan County............	12.6
Group I		
Iowa, No. 2..........	Marion County............	12.4
Illinois, No. 6........	Montgomery County........	12.3
Indiana, No. 2.......	Warrick County............	12.3
Iowa, No. 3..........	Polk County...............	12.3
Illinois, No. 1........	Belleville field.............	12.2
Wyoming, No. 2......	Cambria field..............	12.2
Indiana, No. 1.......	Sullivan County............	11.9
Illinois, No. 4........	Belleville field.............	11.6
Iowa, No. 4..........	Appanoose County..........	11.5
Montana, No. 1......	Red Lodge.................	11.5
Missouri, No. 2.......	Bevier field................	11.3
Iowa, No. 5.........	Lucas County..............	11.2
Group J		
New Mexico, No. 1...	Black Lignite, Gallup field...	11.2
New Mexico, No. 2...	Black Lignite, Gallup field...	11.2
Texas, No. 2.........	Brown Lignite, Wood County.	10.9
Colorado, No. 1......	Black Lignite, Boulder field..	10.6
North Dakota, No. 1..	Brown Lignite, Lehigh field..	10.1
North Dakota, No. 2..	Brown Lignite, Williston field	9.8
Wyoming, No. 1......	Black Lignite, Sheridan field.	9.6
Texas, No. 1.........	Brown Lignite, Houston Co..	9.4

Group K	
Peat	9.1

Table III classifies a large number of the coals tested by the Government at the St. Louis testing plant, according to their carbon-hydrogen ratios.

The information in this table is especially valuable, because the data are obtained from actual analysis and give the comparative values of a large variety of coals covering a wide range of territory. The values of carbon and hydrogen were obtained in each case from an ultimate analysis of the coal and are expressed in per cent., the ratio of the two being obtained by dividing the per cent. of carbon by the per cent. of hydrogen.

This classification proposes dividing the several classes of coals into groups, as indicated by the groups A to L in Table IV. According to this grouping, the present great class of bituminous coals would be divided into four groups. This would give four grades of bituminous coal, where now there is but one, and would separate the low-grade fuels of the Mississippi Valley from the high-class coals of the Appalachian region. For convenience, the proposed groups of coals and allied substances are arranged in Table IV.

TABLE IV.

Grouping of Coals According to Their Carbon-Hydrogen Ratios.

Class of Coal	Group	Ratio $= \dfrac{C}{H}$
Anthracite	A	Over 30
	B	
	C	30 to 26
Semianthracite	D	26 to 23
Semibituminous	E	23 to 20
	F	20 to 17
Bituminous	G	17 to 14.4
	H	14.4 to 12.5
	I	12.5 to 11.2
Lignite	J	11.2 to 9.3
Peat	K	9.3 to (?)
Wood (cellulose)	L	7.2

Under the old classification, bituminous coals cover such a very wide range that their description can be almost anything. They range in specific gravity from 1.25 to 1.4, and in color from a dark brown to pitch black. Also, they range in hardness from that of the lignites to that of the semibituminous. The harder varieties have the best heating values. Generally, they are brittle, with a vitreous, resinous, or greasy luster. The lower grades are higher in moisture, are very liable to disintegrate and crumble, and have a silky appearance, often showing traces of vegetable matter. Bituminous coal absorbs moisture from the atmosphere into the body of the coal if exposed to moisture. The surface moisture will dry off naturally, but the moisture absorbed internally can be driven off only by heating the coal to a temperature of 225° F. to 250° F.

The distinguishing characteristic of the bituminous coals is that they burn with a long, yellow, smoky flame, this characteristic becoming more pronounced with each lower grade of coal. Also, on distillation, the bituminous coals give off hydrocarbon gases, oils, and tars. The long, yellow, smoky flame is due to the fact that large amounts of bituminous matter are given off, and to the fact that not enough air is admitted and intimately mixed with the gases to allow them to burn properly. With a sufficient quantity of air intimately mixed, and with sufficient temperature and time, the gases burn with a shorter, yellow flame and generate much more heat. The effect of an incorrect mixture of air and gas can readily be seen in an ordinary gas range. If the air supply is cut off, the flame lengthens and turns yellow, and smokes, or blackens the kettles with which it comes in contact. Increasing the air

supply to the proper amount shortens the flame; also, it causes the flame to turn blue and be free from smoke, and to generate more heat.

Caking and Non-Caking Coals.—There are two types of bituminous coals, generally designated as caking (cokeing) coals, and non-caking (often called free-burning) coals.

Caking coals are usually very rich in hydrocarbons and are valuable in the manufacture of illuminating gas, the coke of commerce being what remains of the coal after the tarry and gaseous matter are driven off in making the gas. When heated, caking coal swells and becomes fused into a spongy mass that runs together and forms over the fire a cover, or crust, that must be broken up before fresh coal is put on; if this is not done, the crust will not allow sufficient air to pass through the fire to burn the fresh coal. The gas from the coal burns with a bright, yellow or reddish flame, terminating in smoke.

Non-caking coals do not fuse and form a crust, but hold their shape, burn much more freely than the caking coals, and are much preferable for steam purposes. They are generally known as free-burning coals.

Cannel Coal.—Cannel coal is another variety of bituminous coal that is very rich in hydrocarbons. On account of the illuminating qualities of its gaseous matter, it is used extensively to enrich illuminating gas. It is much used, also, as a fuel for open fireplaces. Cannel coal has a specific gravity of about 1.24. It kindles readily and burns with a dense, smoky flame without melting or without loosing its shape, and is of low heating power. Its

appearance differs greatly from that of all other bituminous coals, being homogeneous, with a black or a grayish-black color and a dull, resinous luster. It breaks with a smooth, conchoidal fracture.

Splint Coal.—Splint coal is a non-caking bituminous coal of peculiar structure and low gaseous content. It is of a dull-black color, and much harder and less fragile than caking coal. It is readily fissile, like slate, but breaks with difficulty on cross-fracture. Owing to its slaty structure and low gaseous content, it does not ignite readily, but it makes a hot fire when burning, and constitutes a good house coal.

Indiana Block Coal.—Indiana block coal is a form of bituminous coal laminate in structure, consisting of successive layers of coal easily separated horizontally into thin slices. Between the slices there is a layer of fibrous carbon, resembling charcoal, that makes this separation easy. The coal has a dull, lusterless face on its line of separation, and a glistening, resinous, black face when broken at right angles to the horizontal face.

Subbituminous Coal.—Subbituminous coal, or black lignite, as it is often called, is a grade between lignite and true bituminous coal, and often is not readily distinguished from either by sight. The chief distinction of subbituminous coal is its tendency to absorb moisture if exposed to the weather and to slake, like lime. Also, it checks irregularly on drying, this tendency to check being greatest with the lower grades. Checking not only increases the difficulty of burning the coal, but also reduces its heating value greatly on account of the large stack losses due to moisture and to the difficulty of com-

pletely burning the gases. It usually is black, and often it has a fairly bright luster. The term sub-bituminous is not officially recognized in Canada, coals under that name being known there as black lignites.

Lignites.—Lignite, or brown coal, as it is often called, is vegetable matter in the early stages of coal formation, and, from a geological standpoint, it occupies a position between peat and subbituminous coal. It varies in color from light brown to dark brown, and has a dull and somewhat fatty luster. The light-brown lignites are usually of a distinctly woody structure, whereas the dark-brown lignites merge into the lower grades of subbituminous coal in structure. However, the term lignite is usually restricted to the distinctly brown, woody coals. The ash of lignites varies from 1 per cent. to as high as 57 per cent., and the moisture varies from 10 to 30 per cent., that in freshly mined lignites being often as high as 50 per cent. Lignites run high in oxygen, varying from 8 to 29 per cent. The specific gravity varies from 1.2 to 1.23.

Lignite breaks and crumbles easily on handling and in transportation; therefore, it is generally in a finely divided state and difficult to burn. For these reasons, it must be used within a reasonably short distance from the mines and soon after it is mined, thus making its use limited. In addition, a considerable loss occurs from the fine coal dropping through the grates into the ashpan. Lignite ignites readily and burns rather freely, with a bright, but slightly smoky, yellow flame. It is non-caking, but yields only a very moderate amount of heat.

Peat.—Peat is an accumulation of partly decom-

posed water plants, mosses, and other vegetable matter; hence, it is intermediate between wood and lignite. It is found in bog lands, or marshes, where heat and proper moisture conditions favor the rapid growth of the vegetable matter of which it is composed. The vegetation grows, dies, decays, and is retained in the bog; thus, under proper conditions of heat and moisture it undergoes transformation whereby the oxygen of the vegetable matter, etc., is eliminated, leaving a bed of from 1 to 30 feet of spongy, carbonaceous residue called peat. The denseness of the peat increases with the age and the depth of the bed. The upper layers are of a light, spongy, fibrous nature, ranging in color from yellow to light reddish-brown; the middle layers are more compact and darker in color, while the lower layers are almost black and are still more compact, having scarcely any of the fibrous texture of the upper layers.

When freshly cut, peat contains up to 80 per cent. of moisture, but when air-dried the moisture reduces to about 20 or 25 per cent. It is unfit for fuel, however, until it has been dried. Peat it very high in oxygen, ranging from 17 to about 35 per cent. It varies in ash from 1 to 30 per cent., depending on the amount of ash in the original vegetation and on the quantity of dirt and dust accumulated by the bog.

Sized Coal.—Coal is furnished either as run-of-mine or as sized coal.

Run-of-mine is coal that is in just the condition it was mined; that is, with the lumps and the fine, or slack, coal mixed.

Sized coal is coal that has the lumps separated into different sizes, each size being given a distinc-

tive name, such as egg, nut, etc. For some years the only sizing done on bituminous coal was to separate the very fine coal, called slack, from the lumps. At present, however, a large amount of the better grades is sized in a manner similar to anthracite. Sized coal can be burned to better advantage than unsized coal, because the air for burning can reach the surface of the coal more readily and uniformly. With unsized coal, the small coal blocks the passages between the larger lumps and interferes with the free, uniform admission of air.

Bituminous coal is sized into four sizes that differ somewhat in different localities. They average about as follows: Lump, all sizes over 3 inches; egg, all sizes between $1\frac{1}{2}$ and 3 inches; nut, sizes between $\frac{3}{8}$ and $\frac{1}{2}$ inches; and slack, $\frac{3}{8}$ inch and less.

CHAPTER III

COAL CLASSED ACCORDING TO USE

BESIDES being classified according to their heating values, coals are classified according to the use for which they are best adapted. Commercially, coals are classified as domestic, steam, blacksmith, by-product-coking, producer-gas, illuminating-gas, and cement-burning coals. The steam coals are subdivided into stationary heating-plant and power-plant, locomotive, and steamship coals.

Coals for Domestic Use.—Coals for domestic use are burned in a fireplace, a stove, or a house furnace. Anthracite is best for this purpose, as it is practically smokeless, does not cake, burns with a mild, steady heat with a checked draft and with an intense heat under full draft, and generally results in a finely divided ash that is easily shaken through the grates.

Coals having considerable gaseous matter are objectionable for domestic use, because a large percentage of the gases escape unburned when the fire is low or is checked off and at a low temperature, thus wasting a large percentage of the heating value of the coal. Also, when the fire is checked off there is danger of the gases escaping into the living rooms. When gaseous coals are used, the gases generally burn with considerable smoke, owing to lack of furnace temperature and of sufficient air properly mixed with the gas. The smoke thus produced is objec-

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tionable to the neighborhood, as it fills the air with
soot. If the coal contains much sulphur, the sul-
phur in burning produces, when the draft is low,
stifling gases that corrode the grates and other
metal parts with which they come in contact; also,
the fumes given off from the chimney are very
objectionable to the neighborhood.

**Coals for Stationary Heating Plants and Power
Plants.**—Coals for stationary heating plants and for
power plants must be selected for the equipment and
for the conditions under which the plant is to be
operated. In cities that enforce smoke laws, a coal
high in fixed carbon and low in gaseous products
should be selected. Anthracite is used in the densely
populated districts of many of the Eastern cities;
but, as a general rule, it is not used in steam plants
unless local conditions make its use necessary. In
large power plants using anthracite the coal is gen-
erally fired by means of mechanical stokers, run-of-
mine coal with lumps not exceding 3 inches being
employed.

In central power plants, the load fluctuates
greatly; at times the load is very light, and at other
times the boilers must be forced to their utmost
capacity. Such fluctuations demand a flexible fire
that can be quickly changed to suit the changed con-
ditions of the load. The semibituminous coals are
best for this purpose, as they give off their volatile
gases, about 30 to 35 per cent. of the heat value of
the coal, within 2 or 3 minutes after being placed
on the fire, thus furnishing a quick supply of avail-
able heat to meet sudden increases in the load. The
fixed carbon of the coal burns with a constant rate
of combustion that provides a steady fire for con-
stant conditions. In heating plants, as well as in

power plants where the fluctuations are not so great, the semianthracite proves very satisfactory. When coals, such as anthracite or semianthracite, that are low in volatile gases are used with mechanical stokers, ample boiler capacity should be provided to take care of the excessive loads, because the fire produced with coals of this nature fired with stokers is a constant fire, with less provision for taking care of sudden fluctuations. In localities where the smoke laws are not too rigid, bituminous slack of any of the higher groups of coal proves very satisfactory, as it is practically smokeless with proper draft and proper boiler construction and when fired by means of mechanical stokers.

The low-grade bituminous coals are very high in volatile gases; consequently, they are difficult to burn economically. In some grades, the heat value of the gases is greater than that of the fixed carbon. Where such a coal has to be used, the furnace and stack must be especially designed and properly proportioned to burn the coal as nearly smokeless as possible. Dense, black smoke always indicates a large heat loss due to the escape of a portion of the gaseous matter of the coal unburned and to a deposit of soot on the tubes of the boiler. Good design cannot prevent all this loss, but it will reduce the loss to a minimum, as will be seen by a study of the subject of smoke prevention.

The kind, size, and quality of the coal and the method of firing used are especially important in small hand-fired power plants. The possible losses through poor hand-firing where the high-volatile coals are used is much greater than when mechanical stokers are used. The stoker fires continuously in comparatively small amounts, and it is not necessary

to open the firedoor to fire the coal; consequently, the furnace temperature fluctuates but little and is usually high enough to burn the gases, provided the proper amount of air is admitted and intimately mixed with the gases. With hand firing, the firedoor must be opened to fire the coal, thus admitting large quantities of cold air that tend to cool the furnace. Also, a large quantity of coal may be fired at a time, and this chills the furnace to such an extent that a considerable quantity of the gases escapes unburned. With such a plant, therefore, much money would be saved by using the low-volatile coals, because not so much of the heat value could be carelessly wasted through allowing the gases to escape unburned. If a coal with a high percentage of gaseous matter is used and the gases are distilled off at moderate temperatures, as is the case with many of the younger Western coals, the loss through unburned gases may be very great.

As a general statement, it may be said that if all conditions were such that all the gases of the coal would be burned, the highest efficiency of a boiler would be obtained when using anthracite and this efficiency would decrease with each lower grade of coal. If efficiency in burning, therefore, were the chief consideration, anthracite would rank first as a coal for steam purposes. As a rule, however, a coal must give off sufficient gas to make the fire flexible enough to suit the conditions under which the steam plant must operate. Thus, the actual relative values of the coals for stationary steam purposes do not rank from anthracite downward, but follow in the order given in Table VI.

This table shows that for steam purposes 2 tons of semibituminous coal are worth in heat value

TABLE VI.

Relative Values as Steam Coals.

Kind of Coal	Per Cent.
Semibituminous	100
Semianthracite	93
Anthracite	91
Bituminous (Eastern)	89
Bituminous (Western).........................	67
Lignite	45

about 3 tons of the Western bituminous coal, and nearly 4½ tons of lignite. If the cost of freight and the handling of the coal, as well as the cost of handling the ash, is considered, the comparison is even worse for the lower grades of coal, as will be seen when the ash of coal is considered. Therefore, to develop the rated capacity of a boiler with the different grades of coal, either the grate area or the amount of draft, or both, must be increased in accordance with the position of the class of coal in Table VI. Also, the stack or chimney must be designed not only to produce more draft when the lower grades of coal are used, but also to carry away a much larger volume of gases of combustion, as will be seen when the combustion of the gases of coals is considered.

The best coal to use under a given set of conditions therefore involves a consideration of the type and the construction of boiler, of the draft appliances, and of all conditions affecting the burning of the coal and the economy of the plant. The conditions of combustion so determine the evaporative power of a coal that a coal that gives a high evaporative efficiency under one set of conditions might

give very low efficiency under other conditions. In designing a power plant, therefore, it is very important to know the characteristics of the coal to be used, so that the plant can be designed to produce the best conditions for the burning of that particular coal.

Coals for Locomotive Service.—Coals for locomotive service vary according to the location of the railroad. Many of the Eastern roads burn the smaller grades of anthracite, such as culm, birdseye, fleaseye, etc., a percentage of soft coal usually being mixed with the anthracite. On a majority of the roads, however, the bituminous coals are used.

The firebox of a locomotive is necessarily so restricted, compared with the capacity of the boiler, that the coal burned per square foot of grate area per hour is very high as compared with the stationary practice. Stationary practice ranges from 15 to 25 pounds; whereas, in locomotive service, it is often as high as 150 pounds per square foot of grate area per hour. For good economy, the rate should not exceed 100 pounds per square foot of grate area per hour. As anthracite is a much slower-burning coal than are the bituminous coals, the grate area of a hard-coal engine must be considerably larger than that of a soft-coal engine.

Anthracite should give better economy in locomotive service than bituminous coal. The firebox sheets of the locomotive are surrounded with water that absorbs heat direct from the fire and thus tends to cool the gases below the igniting point; also, the combustion space is very limited and the strong draft produced by the exhaust steam tends to hurry the gases into the tubes before they burn. If the

coal used is high in gaseous matter and a high rate of coal burning is maintained, it will be impossible to admit sufficient air and properly mix this air with the gaseous matter to burn all the gases, and considerable waste will occur through the escape of gases unburned; consequently, the more gas a coal contains, the harder it will be to burn the coal economically and smokelessly. While bituminous coal can be made to produce a more intense firebox temperature by means of the strong draft of the locomotive, the increased temperature is obtained at the expense of economy in fuel. Semibituminous coal gives excellent results as regards forcing capacity, economy, and smokelessness in locomotive service.

Where run-of-mine coal is used, the draft must be as mild as possible, and yet burn the quantity of coal required; otherwise, the cinder loss, due to the fine coal being thrown out of the stack unburned, will be excessive. Also, the grates must be of the proper size and kind for the coal, and care must be exercised in shaking them; otherwise, there will be considerable loss due to fine coal dropping unburned into the ashpan. For best results, the large lumps should be broken to the size of a 3-inch cube. Coal broken into small pieces presents more burning surface than a large lump and will burn up much more quickly. As the capacity of the boiler depends on the rate of burning the coal, this matter is important. Another bad feature of lumps is that they burn very slowly, whereas the fine coal around the lumps burns very rapidly. Thus, the fine coal tends to burn out and form holes in the fire around the lumps, and such holes allow an objectionable amount of cold air to enter the firebox at such points, and correspondingly reduce the amount of air being

forced through the fire by the draft. This condition results in a further reduction of boiler capacity. The coal should be reasonably low in ash for the reasons given in the article on the ash of coals. Coal for locomotive and for marine service must withstand a very high ashbed temperature without forming clinkers.

Coals for Steamship Service.—Coal for steamship service is required to produce a steady, uniform supply of steam, for once the vessel is under way the steam supply remains nearly uniform throughout the trip. Anthracite, therefore, is most suitable for such service, as it delivers up its heat at a practically uniform rate. The coal should be a low-volatile coal of high-heat value, and low in ash so that as large a supply as possible may be stored in the restricted storage capacity of the vessel. Practically all steamship coal is run-of-mine. As in locomotive practice, the lumps should be broken up before firing. The fine-coal-cinder loss is less in steamship than in locomotive service, because the draft is so much less.

Blacksmith Coals.—Blacksmith coal should be a coking coal, as it must form an arch over the metal that is being heated. It should have a high heat value; also, it should be low in ash and extremely low in sulphur, as sulphur corrodes the iron. Broad Top and Tioga County, Pa., coals are standard blacksmith coals.

Coals for By-Product Coking. — Coal for by-product coking must be a coking coal, yielding a volume of gas from 28 to 38 per cent. that is rich in illuminating qualities. In the by-product process, the coal is coked in such a manner that the gas, the

tar, and the ammonia are recovered. Sometimes the gas is the principal product and the others the by-products, and sometimes the coke is the principal product.

When gas is the principal product and the coke is to be used for steam or for domestic purposes, as high as 2 per cent. of sulphur is sometimes permitted in the coal, although the presence of sulphur increases the difficulty of purifying the gas.

When coke is the principal product and is intended for metallurgical purposes, the sulphur content should never be more than 1.5 per cent. Ash is objectionable in coke used for metallurgical purposes, as it reduces to a form of slag at the expense of part of the heat of the coke and thus reduces the heat value of the coke. The coke contains about 3 per cent. more ash than the coal from which it is produced, for which reason the limits of ash in coal for by-product coke has been established at from 6 to 7.5 per cent.

Coals for Producer Gas.—Coal for producer gas varies greatly, gas producers utilizing fuels ranging from anthracite to charcoal and peat. The kind of coal selected depends to some extent on the type of producer and the use to which the gas is to be put. Producer gas provides a supply of cheap fuel that is used principally for gas power, steam, and metallurgical purposes. It is used also in kiln-burning.

Coals for Metallurgical Purposes.—For metallurgical purposes, a gas-coal low in sulphur is preferable, as the gas burns with a long, high-temperature flame that gives a more uniform distribution of the heat.

Coals for Illuminating Gas.—Coal for illuminat-

ing gas is a ¾-inch, screened coal analyzing approximately as follows: Volatile matter, 32 to 37 per cent.; ash, 6 to 8 per cent.; sulphur, up to 1.5 per cent. The coal should yield from 10,000 to 11,000 cubic feet of 18 candlepower gas per 2,000 pounds of coal and about 60 per cent. of coke.

Coals for Cement Burning.—Coals for cement burning should contain enough volatile gases to insure quick ignition and should have a fairly high heat value. Gas coals give the best results, because they burn with a long flame that produces a maximum temperature a short distance within the kiln. Low-volatile, slow-burning coals are unsatisfactory for cement burning. The coal is ground to a powder before it is used, slack coal being employed, as less work is required to powder it. The percentage of sulphur in the coal is not so important, because sulphur will not combine with the cement if the proper kiln temperature is maintained. Low-ash percentage is desirable in that the ash reduces the heat value of the coal.

CHAPTER IV

COMPOSITION OF COAL

COMBUSTIBLE and Non-Combustible.— The value of a coal is measured by the amount of heat per pound of coal that it will generate when burned. The heat value of a coal therefore depends both on the kind and on the relative amounts of its combustible and non-combustible contents. The "combustible" is that portion of the coal which will burn, and consists of the carbon, the hydrogen, the hydrocarbons, and, in some cases, the sulphur of the coal. Part of the carbon is in an uncombined state, and forms the coke of the coal, which is known as the fixed carbon. Some of the carbon is chemically combined with hydrogen and forms gas, oils, and tars, and these are known as the hydrocarbons and as hydrocarbon gases. The fixed carbon and the hydrocarbons are the combustible of the coal. The term volatile matter is used to designate the volatile, or gaseous, matter, exclusive of moisture, that is driven off from the coal. It consists of hydrogen, of the combustible hydrocarbon gases, and of varying amounts of carbon dioxide and nitrogen gases that are non-combustible. These non-combustible materials vary from 1 to 15 per cent. in the volatile matter of different coals.

The non-combustible contents of coal are the moisture, ash, oxygen, and nitrogen.

Fixed Carbon.— The fixed carbon is the prin-

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cipal combustible constituent of coal, and the steaming value of bituminous and semibituminous coals increases up to a certain point with the percentage of fixed carbon they contain. One pound of fixed carbon will generate only 14,500 heat units, whereas 1 pound of hydrocarbon gases will generate 23,500 heat units; yet, on account of careless firing, faulty furnace construction, etc., it is so difficult to burn completely all the gases generated that the heat value of the fixed carbon is relatively greater than that of the volatile matter for coals possessing more than 20 per cent. of volatile matter. For coals having 20 per cent. or less of volatile matter, practically all the volatile can be completely burned; hence, a pound of combustible consisting of 80 per cent. of fixed carbon and 20 per cent. of volatile would have a heat value of .8 x 14,500 + .2 x 23,500, or 16,300 heat units. Decreasing the volatile matter below 20 per cent. decreases the heat value of the coal, because the higher heat value of the hydrocarbons is replaced by the lower heat value of the fixed carbon. For example, 1 pound of combustible consisting of 90 per cent. of fixed carbon and 10 per cent. of volatile would have a heat value of only .9 x 14,500 + .1 x 23,500, or 15,400 heat units. These values are theoretical and can only be approximated in actual practice.

Lord and Somermeir of the U. S. Geological Survey suggest the curve shown in Fig. 1 as showing the practical relation of the heating value per pound of combustible of a coal to the percentage of fixed carbon. The curve is based on data obtained from seventy-eight tests conducted by the U. S. Geological Survey at St. Louis during the World's Fair. It will be noted that a small increase in fixed
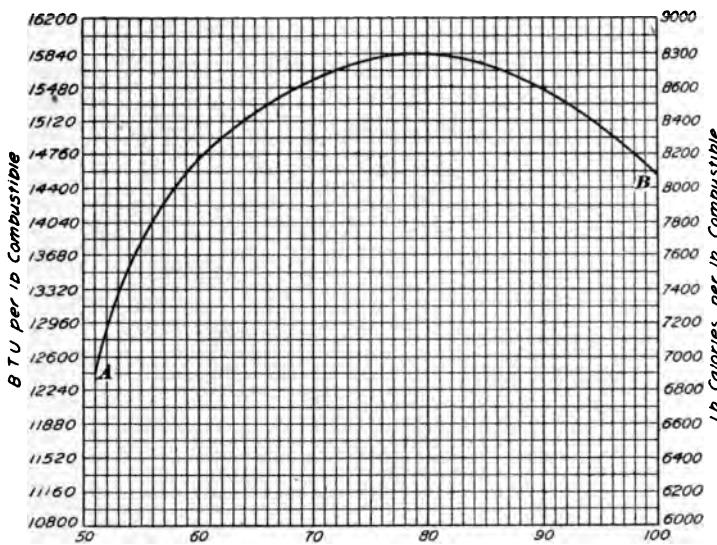
Fig. 1.
Per Cent. Fixed Carbon in Coal.   Dry and Free from Ash.

carbon at the beginning of the curve makes a large
increase in the heating value of the coal.   For ex-
ample, increasing the fixed carbon from 51 per cent.
to 52 per cent. increases the heat value per pound
of combustible about 450 B. T. U.   On the other
hand, increasing the fixed carbon from 72 to 73 per
cent. increases the heat value per pound of com-
bustible only about 50 B. T. U.   The curve shows,
also, that, for steaming purposes, increasing the per-
centage of fixed carbon above 80 per cent. causes a
reduction in the heating value per pound of com-
bustible, as already explained.   The percentages of
fixed carbon in more than 300 different coals are
given in column 12 of Table A in the appendix.

Hydrogen.—Hydrogen, though forming only a
small percentage of the total combustible of coal,

is an important element of combustion, because, in burning, it produces nearly four and one-half times as many heat units per pound as carbon. It is found in the uncombined state in certain fuel gases, but in coal it is more commonly found combined with carbon in the form of hydrocarbons, and with oxygen, in the form of water, as moisture. That part of the hydrogen which is combined as water is of no fuel value, and must be deducted from the total hydrogen in calculating the heat value of the hydrogen of a coal. The hydrogen that remains after deducting that which is combined with oxygen is capable of being burned, and is called the available hydrogen. If a fuel contains both oxygen and hydrogen, it is assumed that all the oxygen is combined with hydrogen in the form of water. Water consists, by weight, of 8 parts of oxygen and 1 part of hydrogen. If, therefore, the oxygen in the coal is 8 times or more the weight of hydrogen, all the hydrogen will be combined with the oxygen and there will be no available hydrogen; if the oxygen is less than eight times the weight of the hydrogen, then the oxygen will combine with one-eighth its weight of hydrogen and the remaining hydrogen will be hydrogen in excess, or available hydrogen. The available hydrogen, therefore is equal to the total hydrogen minus one-eighth the weight of the oxygen. Since oxygen in coal renders one-eighth its weight of hydrogen of no fuel value, it is plain to be seen why high-oxygen coals are of less heat value than coals of low-oxygen content.

From an inspection of column 7, Table A, it will be seen that the variation in the amount of hydrogen in any coal is not great, so that, from the standpoint of the heat value of the coal, the hydrogen

alone need not be given special consideration. It is the relation of the hydrogen to the oxygen that counts. The hydrogen is important in coals high in sulphur, because the general result of high-hydrogen content is the neutralization of the bad sulphur effect. A high-hydrogen, low-oxygen content results in high available hydrogen.

In coking coals, hydrogen is especially importnat, because the adaptability of a coal to coking appears to be indicated by the ratio of the hydrogen to the oxygen contents, on the moisture-free basis. Practically all coals with H:O ratios of 59 per cent. or more possess the quality of coking; the coking property seems to depend on the relative amount of hydrogen to oxygen on a moisture-free basis. With anthracite and semianthracite, the H:O ratio does not always hold, as a relatively high carbon element in the volatile combustible of the coals with more than 79 per cent. of fixed carbon seems to be necessary in order to obtain the best coking results.

Volatile Combustible Matter.—The combustible referred to in connection with the curve, Fig. 1, is the sum of the fixed carbon and the volatile combustible matter of the coal. A combustible containing 52 per cent. of fixed carbon would, therefore, have 48 per cent. of volatile matter; one with 80 per cent. would contain 20 per cent. volatile matter; and so on for the other values of the curve. From the curve, therefore, 80 per cent. of fixed carbon and 20 per cent. of volatile matter appear to give the best results for coals used for steaming purposes. Reducing the volatile combustible matter from 20 per cent. to 0 reduces the heating value of the combustible from 15,840 to 14,580 B. T. U. On the other hand, increasing the volatile combustible mat-

ter from 20 to 48 per cent. decreases the heating value of the combustible from 15,840 to 12,420 B. T. U. The reasons for this were given in the article on Fixed Carbon.

As already mentioned, the results indicated in the curve, Fig. 1, are average results obtained from tests of seventy-eight different coals. As a matter of fact, the volatile content of different coals differs greatly in character. The volatile matter of the younger (Geologically) Western coals includes comparatively large amounts of inert non-combustible material, such as carbon dioxide, and water and correspondingly small proportions of hydrocarbon gases and tarry vapors. Also, larger amounts of gas and tarry vapors are driven off quickly at moderate temperatures when the furnace temperature is low, and this greatly increases the amount of gas that escapes unburned. It is very probable that the greatest heat loss through unburned gases occurs through the escape of the first gaseous products that are driven off, as at that time the furnace conditions are least favorable to the burning of gases.

This loss due to inert volatile matter and to the escape of unburned gases explains the low efficiency usually obtained in burning high-volatile Western coals. The older bituminous coals of the Eastern type yield volatile matter that is low in inert non-combustible matter, but high in hydrocarbons and tarry vapors that are difficult to burn without smoke and without loss through unburned gases, due to lack of temperature, lack of combustion space, and lack of air properly mixed with the gases. These facts explain why a coal like Pittsburg coal is so difficult to burn without producing dense, black smoke. The presence of considerable light hydro-

carbon gas in the volatile matter of Pocahontas coal at low temperatures undoubtedly contributes to the smokelessness of that coal, because the burning of the hydrogen with its high-heat value assists greatly in producing the temperature necessary to the burning of the smoke-producing content of the volatile.

The inert non-combustible matter varies from 4 per cent. of the volatile in an Eastern coal like Pocahontas to 42 per cent. in the subbituminous coals of Sheridan Field, Wyoming.

Therefore, in designing a plant for steaming purposes that is to burn high-volatile coals, it is important that the furnace and draft be adapted to the kind of coal to be burned, and this necessitates a knowledge of the amount and the character of the volatile matter given off at different temperatures. Without this knowledge, the design will be only guesswork, as it is impossible to design a plant for the greatest efficiency without a thorough knowledge of the characteristics of the coal that is to be used.

Gaseous Products at Various Temperatures.— The total quantities of different gases derived from 10 grams of air-dried coal and the quantities given off at the different temperatures is shown in Figs. 2, 3, and 4. The curves are plotted from data of Government tests reported by H. C. Porter and F. K. Ovitz of the U. S. Department of Interior, Bureau of Mines.

Coal No. 1 is an Illinois coal from the No. 7 seam of the Ziegler, Franklin Co. mine. It represents the non-coking interior province coals and ranks high in volatile matter, in heating value, and as a steaming coal.

Coal No. 3 is a Pennsylvania coal from Connells-

ville, Fayette Co., and is a representative steaming coal of the Pittsburg district. It is a coking coal, slightly lower in volatile matter and of higher heat-
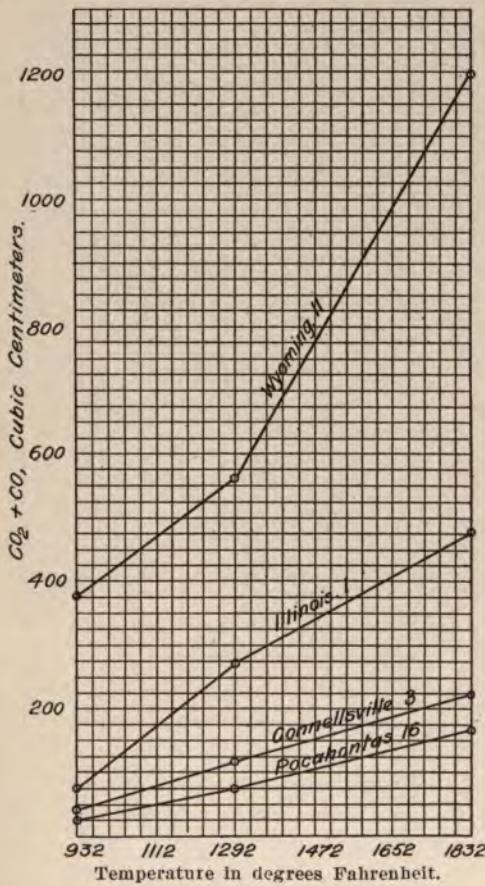
Fig. 2.
Gaseous Products of Coals.

ing value than coal No. 1, and produces more dense, black smoke in burning unless conditions of combustion are favorable for smokeless combustion.

Coal No. 16 is a Virginia coal from Pocahontas, Tazewell Co., and represents the coals of the lower West Virginia region. It is a coking coal, has the
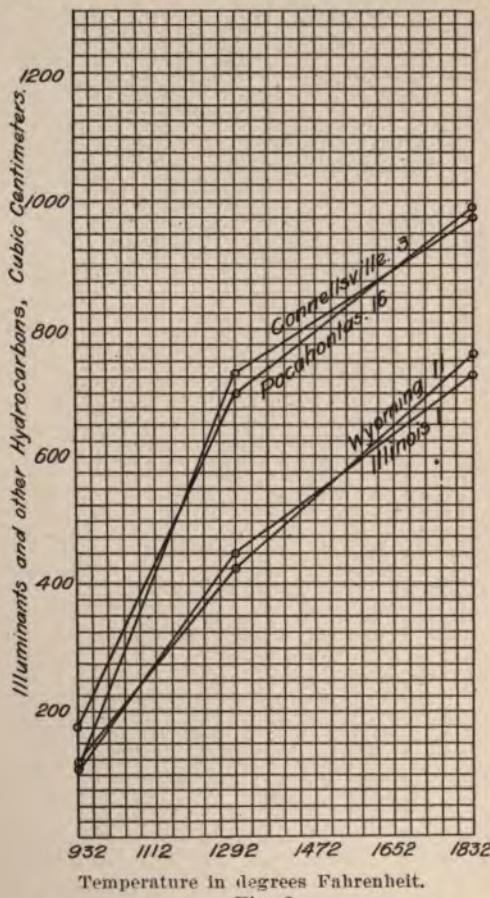
Temperature in degrees Fahrenheit.
Fig. 3.
Illuminants and Hydrocarbons in Coal.

highest heating value of the bituminous coals, is low in volatile, and is one of the so-called smokeless coals. Coal No. 11 is a Wyoming coal from Dietz, Sheri-

dan Co. It is a low-grade, black lignite of low heating value and high oxygen and moisture content; therefore, it gives a very low efficiency when used in

Temperature in degrees Fahrenheit.
Fig. 4.
Hydrogen in Coal.
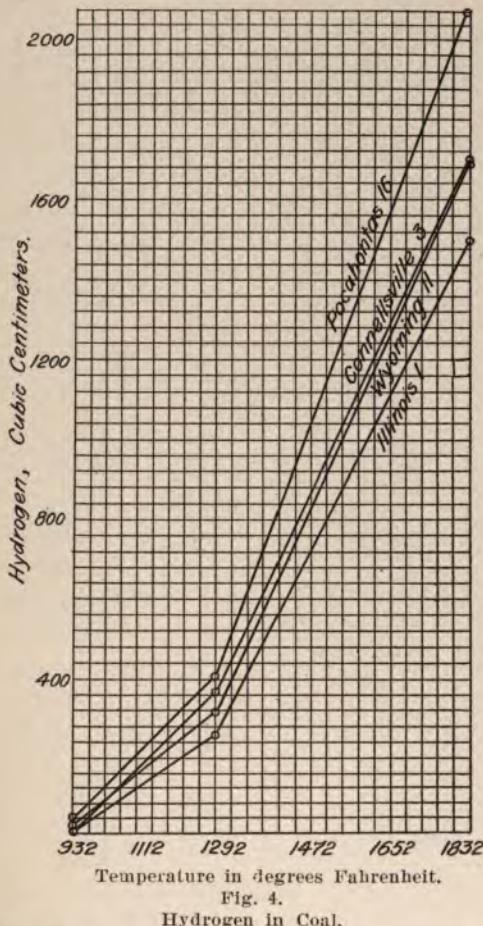
steaming plants. It contains 30 per cent of moisture and slakes badly in weathering.

From Fig. 2 it will be seen that, with the excep-

tion of coal No. 11, the volume of carbon dioxide plus carbon monoxide ($CO_2 + CO$) given off is practically uniform throughout the range of temperature. The Illinois and Wyoming coals, however, give off much greater amounts than the Eastern coals. On the other hand, the Eastern coals, Figs. 3 and 4, give off considerably more hydrocarbons and more hydrogen than the Western coals.

The heavy hydrocarbons, Fig. 3, are given off much faster and in much greater volume from 982° F. to 1,292° F. than above that temperature, thus making them difficult to burn completely and without smoke, as the furnace conditions are not so favorable at the lower temperatures. All the hydrogen, on the other hand, Fig. 4, is practically given off at temperatures above 1,292° F.; therefore, furnace conditions are more favorable for the burning of hydrogen.

The smoky constituents of the volatile matter consist of illuminants and heavy hydrocarbons, as well as tarry matter. Figs. 5 and 6 show the amounts
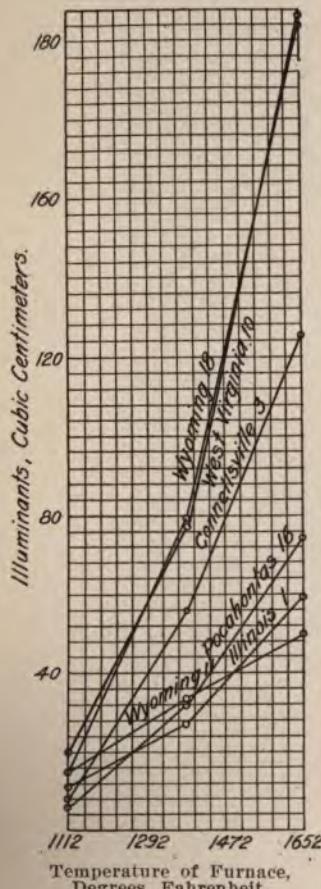
Temperature of Furnace,
Degrees Fahrenheit.
Fig. 5.
Smoky Constituents of
Coal.

of the smoky constituents in 10 grams of air-dried coal and the rates at which they are evolved as the temperature is increased from 1,112° F. to 1,652° F.
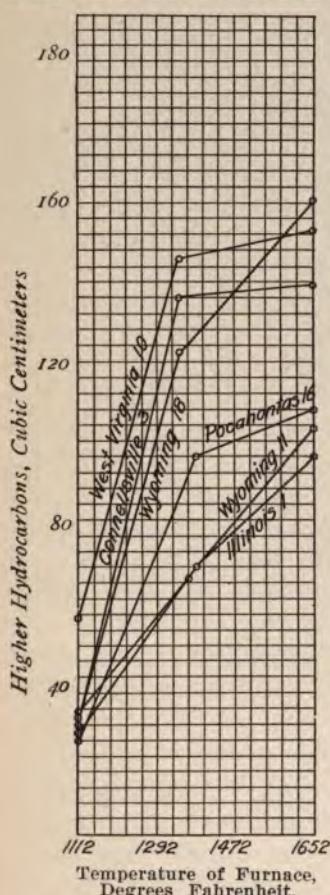
Diagrams of two new coals, Nos. 10 and 18, are added in these figures. Coal No. 10 is a high-volatile West Virginia, Page, Fayette Co., gas coal; coal No. 18 is a "long-flame," high-grade, Wyoming steam coal from Diamondville, Juniata Co.

The smoky constituents, it will be noted, are greatest in the Connellsville, West Virginia and Wyoming gas coals, the heavy hydrocarbons, especially, being evolved quickly and in large volume during the early period of heating. The character and the volume of the volatile given off during the early period of heating have much more effect on fuel economy, on the production of smoke, and on the general efficiency of the furnace than the volatiles produced at the later periods of heating. This is due to the fact that, in early periods of heating, neither the air supply nor the furnace temperature conditions are such as to

Fig. 6.
Higher Hydrocarbons in Coal.

burn all the volatile gases completely. The percentage of volatile matter in more than 300 kinds of coal are given in column 13 of Table A.

Moisture.—Moisture in coal appears as surface moisture, or that which is on the exterior surface of the coal, and as hygroscopic moisture, or that which is held within the pores of the coal by capillary attraction. The surface moisture is readily absorbed by the atmosphere, whereas the hygroscopic moisture can be driven off only by heating the coal to a temperature of from 225° to 250° F.

The quantity of surface moisture that a coal will hold depends on the amount of surface exposed to the weather. Since breaking a lump will increase the surface exposed, it follows that small coal will hold more moisture than large lumps. When wet down or when rained upon, fine coal or slack may hold 10 per cent. of surface moisture.

The capacity of coal to hold hygroscopic moisture varies greatly, even for coals of the same age and district and under apparently the same conditions as to progressive metamorphism. The capacity seems to depend largely on both the character of the original constituent organic matter and the conditions governing the first stages of coal formation. If a portion of the hygroscopic moisture be removed by heating the coal and the coal then exposed to the atmosphere, the coal will slowly reabsorb moisture until, finally, it will contain the original amount.

Moisture exercises an anticalorific influence on coal, by which is meant an influence that reduces the power of the coal to produce heat. Moisture does this in three ways: By reducing the quantity of coal actually obtained by an amount equal to the weight of the moisture; by vaporizing the moisture in the

furnace at the expense of a portion of the heat of the coal; and by then heating the vapor to a furnace temperature and cooling it to the temperature of the escaping gases of combustion, thus absorbing still more heat, which is wasted through the stack.

The anticalorific influence of moisture seems to increase slightly with the capacity of the coal to absorb moisture, as will be seen from Table VII, which is based on data obtained from seventy-nine Government tests of coal from the several localities given.

TABLE VII.

Loss in Heat Value Due to Moisture.

Locality of Coals	Per Cent. of Moisture in Coal	Per Cent. Loss of Total Heating Value of Combustible Due to	
		Moisture in Coal	1 Per Cent of Moisture in Coal
Arkansas.............	1.81	.17	.094
Pennsylvania...........	1.90	.18	.095
Alabama..............	3.69	.40	.108
West Virginia..........	3.72	.24	.064
Kansas...............	4.35	.45	.103
Kentucky.............	6.31	.66	.106
New Mexico...........	9.52	1.11	.116
Illinois...............	11.31	1.37	.114
Missouri..............	12.24	1.56	.127
Indiana...............	12.48	1.43	.114
Iowa..................	13.12	1.66	.126
Wyoming..............	16.46	2.20	.133
Colorado..............	19.78	2.49	.126

From this table it will be seen that while 1 per cent. of moisture in Pennsylvania coal will cause a loss of only .095 per cent. of the total heating value of the combustible of the coal, 1 per cent. of moisture in Wyoming coal will cause a loss of .133 per

cent. of the heating value of the combustible of the coal. The first column of Table VII gives the percentage of moisture in the coals; the second column gives the loss due to the moisture expressed as a percentage of the total heat value of the combustible of the coal; and the third column is obtained by dividing the values in column 2 by the values in column 1, which gives the relative loss due to 1 per cent. moisture in the coal. It will be noted that the relative loss due to 1 per cent. of moisture increases according to the amount of moisture contained in the coal.

The moisture not only reduces the heat value of the coal itself, but also reduces the actual amount of coal obtained per ton. For example, a ton of 2,000 pounds of Wyoming coal, Table VII, would contain $2,000 \times 16.46 = 329.2$, say 330, pounds of water, and only 1,670 pounds of coal. Thus, 330 pounds of water is purchased at coal rates, to which must be added the freight costs and the costs of hauling, handling, and storage.

Also, in burning the coal, the moisture must be heated from normal temperature and vaporized in the furnace, and this requires about 1,100 units of heat per pound of water; the vapor thus formed must then be heated to the temperature of the gases of combustion in the uptake, which absorbs about 165 heat units from the fire, making a total of nearly 1,300 heat units loss per pound of moisture. The loss for 330 pounds of moisture would be $330 \times 1,300 = 429,000$ B. T. U. This represents a loss of $429,000 \div 12,500 = 34$ pounds of coal, so that the loss in coal due to the moisture equals $330 + 34 = 364$ pounds per ton of coal. It is very probable that more heat is carried away with the moisture vapor and com-

bustible gases than is usually attributed to that loss, because the specific heat of the vapor and the gases of combustion probably increases with the temperature. This may explain in part the losses unaccounted for in the heat balance of steaming tests. The loss would be especially high with the low-grade, high-moisture, high-oxygen coals.

The percentages of moisture contained in over 300 coals are given in column II of Table A.

Ash.—Earthy matter and other mineral impurities in the coal that will not burn are classed as ash. Ash, in coal, not only includes the ash contained in the original plant and vegetable matter from which the coal was formed, but also includes silica and alumina in the form of sand, clay, shale, and slate, with varying amounts of ferric oxide, lime, magnesia, potash, and phosphoric acid. Also, it may contain fragments of the roof or floor of the mine or other impurities that become mechanically mixed with the coal in the process of mining or in transportation. The clay, shale, and slaty material can, to some extent, be removed from the coal by hand picking, or they can be removed quite thoroughly by crushing and washing the coal.

Ash, like moisture, is anticalorific in that it reduces the heat value of the coal by taking the place of combustible matter. Therefore, it acts as a dilutent. Also, like moisture, it is bought at coal rates and, in the coal, costs money for hauling, handling, and storage; besides, additional expense is incurred in cleaning the fires and ashpit and in the final disposition of the ash. The worst feature of ash, however, lies in the fact that it not only reduces the heating power of the coal on the grate, but also acts as an obstruction to the flow of air and distrib-

utes the air unevenly through the bed of fire, thus reducing the rate of combustion still more. In other words, for every 100 pounds of coal containing 15 per cent. of ash that is fired there would be less than 85 pounds of combustible burning; also, the 15 pounds of ash would block the air passages in the fire and make the combustible burn more slowly than it otherwise would, besides disturbing the uniform distribution of air through the bed of coal in the furnace. The rate of combustion, therefore, is reduced in two ways by the action of the ash, and results in a reduced boiler capacity.

With ordinary furnace equipment, there will be considerable loss in boiler capacity through a large percentage of ash, and with some of the poorer equipments there probably will be a drop in both boiler efficiency and boiler capacity.

Besides the mineral non-volatile ash that all are familiar with, there is a portion of the ash that is volatile. This volatile portion is the water of hydration or other volatile matter chemically combined with the mineral substance in such a manner that it is driven off when the ash is at a red heat. For example, the combined water in the shale, clay, slate, etc. is driven off and does not show up in the ash; lime in the ash, either as calcium carbonate or otherwise, loses carbon dioxide when heated; also, chlorine, as alumina combined as clayey matter, or in any other form, would be volatile.

The quantity of lime in the ash is indicated by the amount of carbon dioxide in the volatile; whereas, the quantity of alumina is indicated by the amount of chlorine. These volatile non-coal contents, in ordinary methods of coal analysis, are classed with the volatile combustible matter and do not show up

in the ash; consequently, coals high in these contents receive a higher heat rating than they deserve.

From column 10, Table A, it will be seen that the ash in more than 300 coals ranges from 1.68 per cent. to more than 25 per cent., the higher values in the table being for screenings and slack. The ash in 204 other samples of coal arranged according to the sizes of the coal, is shown in Table VIII, which is compiled from data of Government tests.

<div align="center">

TABLE VIII.

Ash From Different Sizes of Bituminous Coals.

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Size of Coal	Total No. of Samples	Number of Samples Containing Ash, Between							
		2-5 %	5-8 %	8-10 %	10-13 %	13-15 %	15-20 %	20-25 %	25-30 %
Slack	49	0	4	4	7	8	17	7	2
Run-of-mine .	13	4	3	3	2	0	1	0	0
Nut	58	2	16	16	14	4	4	2	0
Pea	4	0	0	2	0	0	2	0	0
Lump	60	7	24	14	12	3	0	0	0
Total.....	204	13	47	39	35	15	24	9	2

It will be observed that the ash in slack is high in a majority of cases, varying from 10 to 25 per cent. The ash in the run-of-mine is fairly low, in most cases varying from 2 to 10 per cent. The nut and lump appear to run higher, most of the coal ranging from 5 to 13 per cent.

The total quantity of ash in shipments of the same coal may vary considerably because of lack of care in removing the dirt, shale, rock, slate, etc. that accompanies the coal as it comes from the mines. The lumps of coal may average 5 per cent. of ash; whereas, the coal as shipped may average 15 per cent. owing to the dirt, etc. Usually, the per

cent. of ash in the smaller coals and in run-of-mine is larger than in the sized coals. Coals with less than 10 per cent. of ash is considered good, marketable coal.

Rock, Slate, and Bone.—Anthracite, whether for domestic or for steam purposes, is allowed by the standard specifications to carry a certain percentage of rock, slate, or bone, according to the size of the coal. A piece of coal containing hardly any carbon is classed as rock; a piece containing less than 40 per cent. of carbon is classed as slate; a piece containing from 40 to 65 per cent. of carbon is classed as bone; and a piece containing over 65 per cent. of carbon is classed as coal.

Broken or grate coal is allowed 1 per cent. of slate or rock, and 2 per cent. of bone.

Egg coal may contain 2 per cent. of slate or rock and 2 per cent. of bone. Also it must be free from mud or discoloration.

Stove coal may contain 4 per cent. of slate or rock and 3 per cent. of bone. It must be free from mud and fairly free from discoloration.

Chestnut or nut coal may contain 5 per cent. of slate or rock and 5 per cent. of bone. It must be free from mud or discoloration.

Pea coal may contain 10 per cent. of slate or rock and not much more bone than slate. Its color must be fairly bright.

Buckwheat No. 1 may contain 15 per cent. of slate or rock and not so much bone as to make the mass look dull in color. It must be washed free from mud. If it is washery coal, the ash is counted in with slate, and it must not contain more than 2 per cent. of ash.

Rice coal may contain up to 20 per cent. of slate.

Barley coal must present a fairly bright appearance.

A piece of coal free from bone, slate, or rock will burn to a fine ash unless the ash fuses and clinkers. Bone, slate, and rock maintain their form and appear in the ash in nearly their original size. An inspection of the ash, therefore, gives a good idea of the quantity of bone, slate, or rock in the coal.

Commercially pure coal free from bone, slate, and rock will burn to a fine, white ash that is light in weight and small in bulk. If the coal contains iron pyrites, the ash will be of a reddish color, will be heavy, and will contain clinkers. If the coal contains bone, slate, or rock, the ash will indicate it by the pieces that are in the ash; also, the ash will be heavy and of considerable bulk.

Oxygen.—By reference to Table I, it will be seen that each step in the conversion of organic matter into coal is accompanied by the elimination of a part of the original oxygen of the organic matter that entered into the coal in its formation. Beginning with more than 40 per cent. of oxygen in the cellulose and lignose that comprises the bulk of the organic substance of coal, the amount reduces with each higher grade of coal until, in anthracite, it is only about 4 per cent. Each step in the elimination of the oxygen is accompanied by an increase in the per cent. of carbon, and, consequently, in the heat efficiency of the coal. Oxygen, therefore, is an original impurity in coal that detracts from the value of the coal, and its elimination results in increased heat value.

A comparative study of numerous ultimate coal analyses of the U. S. Geological Survey by David White, supplemented by calorimeter tests, seems to

indicate that the anticalorific effect of oxygen in coal is nearly equal to that of the same weight of ash, the ash probably being slightly more injurious in most coals; that is, the calorimeter tests seem to show that if two coals have the same carbon content, one having 15 per cent. of ash and 4 per cent. of oxygen and the other 15 per cent. of oxygen and 4 per cent of ash, their heat efficiency will be nearly the same. Furthermore, the negative value of the oxygen of moisture in the coal does not seem to differ much from that of the oxygen combined in the coal. In the lowest grades of bituminous coal, and for the grades of coal lower than that, it is probable that the oxygen is slightly more anticalorific than the ash; in the higher bituminous and the semibituminous coals, the ash has probably the higher anticalorific value.

As oxygen and ash are approximately of equal anticalorific value, the efficiency of coals are found to conform fairly close to the order of the ratio of their carbon—to their ash plus their oxygen. From an inspection of column 14, Table A, it will be seen that among coals of all kinds those having the same ratio of C to O + ash are found to have very nearly the same efficiency.

Sulphur.—As a coal constituent, sulphur differs greatly both in quantity and in the condition in which it occurs. It is found in coal in four principal chemical conditions: As iron pyrite, or marcasite; as sulphates of iron, lime, and alumina; as organic sulphur, that is, combined with carbon, hydrogen, and oxygen; and, in rare instances, as free sulphur, that is, sulphur that is not in combination with other elements.

In some coal beds, pyrite is found in balls, bands,

and lenses. In other coal beds, it occurs throughout the lumps of coal in veinlets or as small particles. In weathered coal, sulphur is found combined as sulphates of iron, lime, and alumina. When exposed to the air, pyrite and marcasite tend to absorb oxygen and form sulphate of iron.

The heat effect of the sulphur depends on the quantity, on the state of occurrence, and on the available hydrogen present. Free sulphur is comparatively harmless and may exert its full heat value. In the form of pyrite or marcasite, or other sulphides, its heat value is lessened by combination, and differs with surrounding conditions. As a sulphate, sulphur is of no fuel value. As the heat value of sulphur is very much less than that of carbon, sulphur, even in its most favorable form, reduces the heat value of the coal, unless it is compensated by high available-hydrogen content. From a comparison of columns 7 and 9, Table A, it will be observed that, fortunately, coals high in sulphur are as a general rule also relatively high in hydrogen. The high hydrogen usually results in neutralizing the bad effect on the heat value of the coal of high sulphur content.

Aside from its effect on the heat value of the coal, high sulphur content in coal is injurious to the metal of the boiler, because the products of its combustion, sulphurous acid, attacks the metal of the boiler, particularly in the presence of moisture. The sulphurous acid is transformed into sulphuric acid under the action of the moisture, and attacks the iron, producing sulphate of iron.

Nitrogen.—Nitrogen is an inert gas; hence, it acts as a dilutent in coal. By an inspection of column 5, Table A, it will be seen that the percentage

of nitrogen in coal is quite low, averaging only 1.21 per cent. for the 319 samples in the table. It is quite uniform in amount for each kind of coal, but differs slightly for the different groups. It is highest in the peats and succeeding low grades of coals, and lowest in the anthracites and graphites. As it is present in such small quantities, and as it varies so little in amount in the same kinds of coals, it is of but relatively small importance in the study of fuels and in the purchases of coal.

CHAPTER V

EFFECT OF SIZE OF COAL

IN GENERAL, it may be said that, other things being equal, the coal obtainable at the lowest price is the most economical, provided the furnace and the draft equipment are designed for the use of the kind and grade of coal selected. The size of coal to be used in a given plant, however, must be considered, because the size influences the capacity of any given equipment, owing to its effect on the draft. Coal of uniform size will give the best satisfaction, as it does not pack so closely as coal of different sizes and will therefore burn more freely and will give greater boiler capacity for a given draft. With pea coal or with larger sizes, no difficulty should be experienced in developing the full capacity of a boiler, provided the plant is properly designed. However, with the finer sizes, much difficulty will be encountered in burning the coal so as to obtain full boiler capacity, unless, of course, the plant is very carefully designed for the purpose.

The weight of air per pound of combustible consumed is much greater for the fine sizes than for the larger sizes of coal, and the excess air is nearly twice as great. Also, with fine sizes, the rate of combustion is limited by the rate of air supply that will lift the coal and disrupt the fuel bed so as to permit air to pass through the bed without coming into contact with the fuel. Just as soon as the fuel bed is dis-

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rupted, the rate of combustion decreases and there rushes through an excess of air that results in a drop of the boiler capacity. The rate of combustion will increase as the draft is increased up to the point of disruption, after which increasing the draft will result in decreasing the boiler capacity. The greatest rate of combustion that can be obtained with a fine coal without disrupting the fuel bed is called the maximum rate of combustion for that size of coal, and the finer the coal the lower its maximum rate will be. As the maximum rate of combustion per square foot of grate area is limited for fine coal, sufficient grate area must be provided to burn the required amount of coal to develop the full capacity of the boiler.

Large sizes of coal stand shipping and storing better than small sizes and are better adapted to a wider range of furnace conditions.

EFFECTS OF WEATHERING COAL

Loss of Calorific Value.—Storage of coal has become a necessity, in order that a sufficient reserve supply may be on hand to enable the industrial interests of the country to run without interruption in the event of labor troubles, car shortages, or other unforeseen circumstances that might temporarily prevent the delivery of coal. It has been commonly believed that coal in storage and exposed to the weather for a considerable time loses much of its heating value. Careful experiments, however, by Parr and Wheeler and others, seem to indicate that the loss is not nearly so great as has been imagined.

Coal may be stored in the open air, in covered bins, and under water. The loss through storage may occur through change in weight, through loss

in calorific value, through disintegration, or through spontaneous combustion.

Anthracite is practically unaffected by weather, except for the oxidation of the sulphur content, which is small. It is broken somewhat through handling, but is not subject to spontaneous combustion. There is practically no limit, therefore, to the size of the piles in which anthracite may be stored.

The effect of weathering bituminous coals depends on the nature of the coal. The weight of the coal, in some cases, may be either increased or decreased, depending on conditions. Atmospheric oxidation of the coal proceeds slowly, but continuously, under ordinary temperatures; usually, it does not produce any sensible increase in the temperature of the pile, owing to the radiation that is going on at the same time. However, it results in a decrease in weight and in the heat value of the coal. At higher temperatures, and with certain coals, the rate of oxidation is very much increased, and this tends still further to accumulate heat in the pile and may result in a temperature sufficient to ignite the coal. The coals most readily oxidized in the air are the ones that change most in weight and are more subject to spontaneous combustion. The higher the temperature to which the pile is raised, the greater will be the resulting loss in weight and in heat value of the coal. As a general rule, however, very little change in weight occurs unless the coal heats considerably.

Atmospheric oxidation may or may not result in a visible change in the coal, depending on the impurities contained in the coal. If pyrite, marcasite, or some other inorganic impurity is present, visible changes will occur because of their oxidation. The iron sulphide of the coal will combine with the oxygen

of the air and form sulphate of iron and sulphuric acid.   The sulphuric acid will then unite with the calcium and the magnesium of the coal and form, respectively, gypsum and magnesia sulphate.   This change will result in an increase in the bulk of the pile and will cause disintegration of the coal; also, there will be a considerable increase in the weight of the coal unless the leaching action of the water compensates for the increase in weight.

If the inorganic impurities are not present, no effect of the oxidation will be visible except that, in some coals, after long exposure, the color will become dull and of a brownish hue, similar to that of brown lignite.

The loss in the calorific value of the coal is most rapid during the first few weeks after mining, after which this loss decreases at a constant rate; also, the finer the coal, the greater the loss seems to be.   The loss in screenings is larger than in nut coal, and so on.   The loss for Illinois coal for 1 year was found to be 2.76 per cent. when exposed to the weather, 3.14 per cent. in covered bins, and 1.49 per cent. when stored under water.   It is possible, therefore, that for the Illinois type of coal the calorific loss through storage will not exceed 3 per cent. in 1 year.   The greatest loss occurs during the first 6 months.

Disintegration.—Weathering disintegrates the lower grades of coal, causing them to slake or to break into fine pieces. Such disintegration greatly increases the loss in transportation and renders efficiency in burning the coal very difficult.   The value of such coals, therefore, may be very greatly diminished by exposure to the weather, even though the calorific value may be practically unchanged. Disintegration might change a coal of a suitable size

to one of a smaller size that could not be burned economically in the plant for which it was originally purchased. Weathering also destroys the coking properties of coal. Coal stored out of doors disintegrates more than coal protected from the elements. The disintegration is due to small cracks made by the shot that was fired at the time the coal was mined, to the action of frost, and to the breaking up of the lumps by the action of pyrite and marcasite in oxidizing. Probably the best way in which to prevent such disintegration is to store the coal under water, thus entirely overcoming the action of frost. Coal is much more frail after storage than when freshly mined, and breaks and crumbles more easily in handling.

When coal is stored in piles subject to weather conditions, it is found that the weathering does not extend into a coal pile more than 12 to 18 inches, the depth depending on the length of time that the coal has been stored. The outer layers oxidize and slake and thus form a protective coat that serves to shield the inner coal from the effects of weathering.

Spontaneous Ignition.—Most bituminous coals will ignite spontaneously if stored in large enough piles. Such ignition is due to the heat produced by the absorption of oxygen by unsaturated hydrocarbons of the coal and by the oxidation or slow cumbustion of carbon, sulphur, and available hydrogen, in an air supply that is sufficient to support oxidation, but is not sufficient to remove entirely the heat that is produced in the process. This absorption and oxidation goes on continuously, and the resulting temperature of the pile depends on the rate of production of heat and the rate of radiation of the heat from the pile. Bituminous coal, especially when

freshly mined, has an affinity for oxygen which it absorbs with the evolution of heat. This heat tends to raise the temperature of the pile to the point where slow oxidation begins, after which the rise in temperature of the coal pile is comparatively rapid. The rate of oxidation depends on the porosity of the coal, on the amount of the surface of the coal exposed to the oxygen, and on the temperature of the interior of the pile. As porous and fine coals expose more surface than is exposed by lump coal, they are much more liable to ignite spontaneously. The interior temperature of the pile depends on the rate of oxidation, on the amount of radiating surface of the pile as compared with the cubical contents, and on the circulation of air through the pile. Lump coal permits of a better circulation of air through the pile; therefore, it is easier to keep cool and is much less liable to ignite spontaneously. The radiating surface of the pile decreases with the size of the pile; hence, the interior of a shallow pile will be cooler than the interior of a deep pile.

Oxidation generates heat, which, if not radiated, tends to increase the temperature and, thus, the rate of oxidation; this tends further to increase the temperature, which, in turn, hastens the oxidation. This cycle is repeated until the pile assumes a natural temperature, depending on its size, contents, and radiating surface. The higher this temperature becomes, the greater is the danger of spontaneous combustion. Animal matter, vegetable matter or fats in the body of the pile greatly increase the danger of ignition. The close proximity of an external source of heat, such as a steam pipe or a chimney flue, even though moderate in degree, may produce spontaneous combustion. Under favorable condi-

tions, the direct rays of the sun may be sufficient. Abnormal quantities of moisture, especially when the coal is alternately wet and dried through storms, etc., accelerate the process of absorption of oxygen and promote spontaneous combustion. The ground on which the pile rests should be dry when the coal is stored, because moisture from below is especially conducive to spontaneous combustion.

Prevention of Spontaneous Combustion.—Spontaneous combustion may be prevented by taking proper precautions. The coal should be screened so as not to contain a large amount of fine coal, and care should be taken not to break the coal during handling and storing. If mixed lump and fine coal must be stored together, the various sizes should be evenly distributed, so as to prevent the formation of air passages through segregated portions of the large sizes. When stored indoors, the pile should be in a fireproof bin 25 feet or more removed from the furnace, and there should be no steam pipe nor other source of heat near it.

The height of a flat-top pile should be 6 feet or less for the lower grades of coal, and should not exceed 12 feet for the best grades. Where space permits, a good plan is to store the coal in piles in the form of long, narrow ridges separated by open spaces, to allow air cooling. In hot climates, where the coal would be subject to the heat of long, hot spells, the piles cannot be so high or so large as those in cooler climates. The coal should be mined at least 1 month before storing, and should not be loaded or stored in wet weather nor during hot weather. July and August, therefore, are not suitable months for storing coal.

High-volatile coals sustain greater weathering

losses and are more prone to spontaneous ignition than low-volatile coals. The coals from Texas and from parts of Arkansas are very liable to spontaneous combustion, whereas Oklahoma, Missouri, Kansas, Illinois, and Northern Arkansas coals can be safely stored with proper precautions. Pennsylvania, West Virginia, Ohio, Kentucky, Alabama, and Tennessee coals when properly screened and piled are in very little danger of spontaneous combustion. Colorado, Wyoming, and New Mexico coals can safely be stored when proper precautions are observed.

The conditions favorable to spontaneous ignition are porous or fine coal, the presence of moisture, a high sulphur content, occluded combustible gases, high temperature, alternate wetting and drying, and free access of air without ventilating effect.

Temperature of Coal Pile.—The temperature of the pile at different points can be obtained as follows: Screw a ¾-inch auger to an iron pipe of slightly smaller diameter, and place a maximum temperature thermometer within the pipe. Bore into the pile at the points deemed necessary, and let the pipe stand for 20 minutes so as to be sure to record the maximum temperature. The auger can be driven 8 to 10 feet per minute.

In very large piles, permanent pipes into which the thermometer can be lowered are placed at points in the pile and records are kept of the temperature of the different points.

When the temperature at any point reaches 140° F. to 150° F., action is at once taken to protect the pile, as oxidation increases very rapidly above that temperature. A trench of sufficient width and depth is dug to uncover the source of the high temperature.

Extinguishing a Coal-pile Fire.—To extinguish a coal-pile fire, the coal must be removed from around the burning part and spread out. Water can then be effectively used on the burning part. The fire is always in the interior of the pile, and a crust forms above it that prevents the water from reaching the seat of the trouble; hence, the fire cannot be put out by drenching the pile.

Where coal is to be stored in piles for 2 months or more, the interior temperature of the pile should be taken frequently, because ignition generally takes place within 90 days after storing.

CHAPTER VI

CLINKERING OF COAL ASH

FORMATION OF CLINKER.—The formation of clinker is one of the worst troubles that has to be contended with in the combustion of coal. A knowledge of the degree of fusibility possessed by coal ash, therefore, is often of greater importance to the coal consumer than is the number of B. T. U. in a pound of the coal, since, under certain conditions, a coal may clinker so badly as to be absolutely useless for furnace combustion. The seller of coal guarantees to deliver coal of a certain heat value, and he should be required to guarantee that the ash of the coal delivered shall not fuse below a certain desired temperature, depending on the furnace conditions and on the kind of service under which the coal is to be burned. Clinker affects both the capacity and the efficiency of a plant, as well as the cost of firing and the cost of repairs to the plant and its equipment; hence, a thorough knowledge of clinker formation is of the utmost importance to the consumer, as well as to those directly connected with the operation of a plant.

Clinker is formed either by the chemical combination of the constituents of the ash, thereby forming a slag, or by the fusing, or melting, of the ash of the coal. Every ash has a fusing temperature. Whether an ash may clinker through fusion will

depend on whether the temperature to which the ash is subjected is above or below the fusing temperature of the ash. An ash having a fusing temperature of 2,700° F. or more will rarely give trouble from clinkering if the furnace is fired properly, since furnace temperatures seldom exceed that amount. If the fusing temperature of the ash is below 2,700° F., trouble will be experienced, and the lower it is below that temperature the greater will be the trouble from clinker.

TABLE IX.

Constituents of Coal and Lignite Ash.

Kind of Coal.	Total Ash. Per Cent.	Constituents of Ash, Per Cent.							
		SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_2	MgO	K_2O	Na_2O
Anthracite	7.26	25.66	27.03	42.83	1.56	.17	11.83	....	....
Semibituminous..	7.50	54.80	29.20	6.80	1.40	1.00	.60	2.10	1.90
Bituminous	17.40	47.30	34.60	9.80	1.20	.10	.40	2.50	2.10
Bituminous	8.20	15.20	8.60	13.30	18.10	26.90	10.00	1.80	5.30
Slack, Bitumin...	11.40	53.20	26.00	15.80	1.00	.40	.70	1.60	.30
Lignite..........	16.60	39.30	24.08	3.80	14.90	12.50	1.70	.40	.10

Constituents of Ash.—Ash is a mechanical mixture of silicates, oxides, and sulphates, in which the percentages of the different constituents vary greatly. The silica, however, predominates in most cases. Ash is composed largely of oxide of silica, SiO_2; oxide of alumina, Al_2O_3; oxide of iron, either as ferrous oxide, FeO, or as ferric oxide, Fe_2O_3; oxide of lime, CaO; and oxide of sulphur, SO_2. Also, it contains

small percentages of oxide of magnesium, MgO; oxide of sodium, Na_2O; and oxide of potash, K_2O.

It will be seen from Table IX that the composition of ash varies greatly. However, the values in the tables are not given as limits to the range of variation, but merely as examples of variations in the composition of ash.

Clinker is of two types, designated either as hard clinker or as soft clinker. Hard clinker is formed by the direct melting of the ash or of some of its constituents. It hardens while in the ash on the grates. If formed through a portion of the ash melting, it will be in the form of a large, hard cake at some point on the grate. If formed through certain constituents of the ash melting, it will be found as a number of small, hard clinkers distributed throughout the ash.

Soft clinker remains molten while on the grates, but hardens when its temperature is sufficiently reduced. Once formed, the soft clinker continues to grow in size until practically the entire grate is covered.

Soft Clinker.—Soft clinker is a slag formed by the combining of the silica of the ash with the most fusible constituents of the ash. Silica is infusible at ordinary temperatures; see Table X. Also, the basic oxides of the ash are refractory materials and are quite infusible at furnace temperatures. However, the basic oxides act as fluxes for the silica and promote the fusing of the silica. The silica acts as an acid flux, whereas the oxides act as basic fluxes.

When two or three of the basic oxides are brought together in the presence of silica, a given temperature, depending on the proportions of the ingredients and on their melting temperatures, will

cause them to fuse and slag and form a silicate that is called clinker. To bring about this union, sufficient heat must be supplied to cause the fusion. A silicate containing one base is usually less fusible than one containing two bases, and much less fusible than one containing three bases, the same proportion of silicate to base being used in the three cases. Silica melts at 3,227° F.; a silicate formed by the combination of FeO and SiO_2 fuses at 2,318° F.; if part of the iron of this silica is replaced by 16 per cent. CaO, the resulting iron-lime-silicate will fuse at 2,138° F.

TABLE X.

Fusing Temperatures of Oxides.

Oxide	Formula	Atomic Weights	Fusing Temperature	
			Degrees C	Degrees F
Silica............	SiO_2	60.30	1,775	3,227
Alumina.........	Al_2O_3	102.20	1,880	3,416
Ferrous.........	FeO	71.84	1,419	2,586
Ferric..........	Fe_2O_3	159.68	1,560	2,840
Lime............	CaO	56.07	1,900	3,452
Magnesia........	MgO	60.32	2,250	3,882
Sodium..........	Na_2O	62.00	700	1,292
Potash..........	K_2O	94.20	900	1,652

Silica-Iron-Lime Slags.—Table XI* gives the formation temperatures of various silicate-iron-lime slags, in which the lime content is increased from 0 to 52 per cent. The curve, A, Fig. 7, is plotted from this data. From the curve it will be seen that with no lime content, the ferrous silicate forms at 2,318°

*Report of Investigations by Prof. H. O. Hofman, Inst. of Tech., Boston, Mass., on the formation temperature at which ferrocalcic silicates are formed, T. A. I. M. E. Vol. 29, Pg. 704.

TABLE XI.

Formation Temperature of Silica-Iron-Lime Slags.

Chemical Composition of Slag			Equivalent Per Cent. on Si(FeO, CaO)		Melting Point	
SiO₂. Per Cent.	FeO. Per Cent.	CaO. Per Cent.	FeO. Per Cent.	CaO. Per Cent.	Seger Cone. No.	Degrees C.
29.20	70.80	0	100.00		7	1,270
29.75	66.25	4	92.80	7.20	6	1,250
30.09	61.91	8	85.75	14.25	5½	1,240
30.42	57.58	12	78.87	21.13	4½	1,220
30.76	53.24	16	72.12	27.88	2	1,170
31.07	48.93	20	65.55	34.45	3¾	1,205
31.40	44.60	24	59.12	40.88	3	1,190
31.70	40.30	28	52.80	47.20	2	1,170
32.10	35.90	32	46.60	53.40	1	1,150
32.30	31.70	36	40.66	59.34	1	1,130
32.70	27.30	40	34.67	65.33	1	1,150
33.10	22.90	44	28.81	71.19	3	1,190
33.44	18.56	48	23.12	76.88	7	1,270
33.79	14.21	52	17.55	82.45	15	1,430

F. Adding CaO uniformly lowers the formation temperature up to 16 per cent. of lime. Increasing the lime from 16 to 20 per cent. raises the temperature of formation to 2,200° F. Increasing the lime above 20 per cent. again causes the formation temperature to be lowered until, with 36 per cent. of CaO, the temperature is only 2,066° F. Further addition of CaO causes the formation temperature to rise rapidly.

The curve shows clearly that the formation temperature of an ash mixture depends on the relative proportions of the constituents of the ash. Also, it shows (point a on the curve) that with a certain mixture the formation temperature may be several hundred degrees lower than the fusing temperature of

any of the constituents of the ash. Such a mixture is called an eutectic mixture, by which is meant a compound substance having its components mixed in such proportions that the formation temperature of
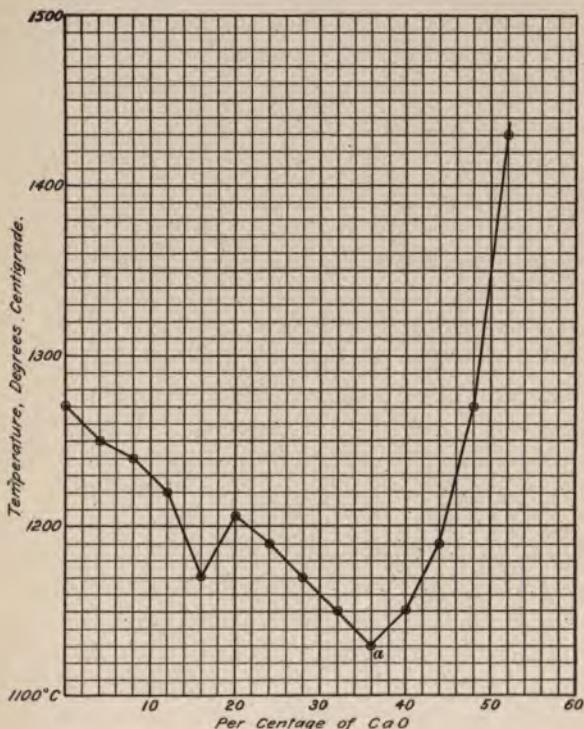
Fig. 7.
The Formation of Ferro-Calcic Silicates.

the compound is lower than the fusing temperature of any of its components.

In the fourth and fifth columns of Table XI, the percentage of equivalents of FeO and CaO is given in order to show the relative fluxing effects produced by the chemical replacement of the FeO by the CaO.

This is calculated as follows: From Table XI, fourth row, $SiO_2 = 30.42$; $FeO = 57.58$; and $CaO = 12$. The molecular weight of FeO is 71.84; that of CaO, 56.07; therefore, $\frac{57.58}{71.84} + \frac{18}{56.07} = .801 + .214 = 1.015$. This number, to be reduced to 100, must be multiplied by 98.52, since $1.013 \times 98.52 = 100$. The FeO, therefore, equals $.801 \times 98.52 = 78.92$ per cent. The $CaO = .214 \times 98.52 = 21.08$ per cent.

The Seger cones mentioned in the sixth column of the table will be explained later.

Influence of Ash Constituents.—The tendency of an ash to slag depends on both the ratio of silica to basic oxides and the fusibility of the bases. The fluidity of a slag depends on the character of the basic oxides of the ash, and on the amount of superheating the silicate is subjected to. A slag may be very viscous at the formation temperature, yet it may become quite fluid when superheated.

Silica.—Silica, increased from 18 to 30 per cent. does not have much influence on the formation temperature of a silica-iron-lime slag, the silicate fusing at 2,174° F. As the silica is increased from 30 to 48 per cent. and the base reduced from 70 to 52 per cent., the formation temperature falls almost uniformly to 2,057° F. Increasing the silica to 56 per cent. causes another gradual drop of temperature to 2,028° F. Increasing the silica above 60 per cent. causes an abrupt rise of temperature to 2,390° F.

Slags with a low percentage of silica have a slightly higher formation temperature than those with higher percentages of silica, but they are very fluid as soon as the formation temperature is

reached. Slags having a high percentage of silica fuse down very slowly, carry uncombined silica, and are light, but very viscous, or pasty.

Alumina.—Alumina replacing silica in an iron-lime silicate has the effect of gradually raising the formation temperature. Also, the slags become less fluid, are opaque, and change from a dark reddish-brown to a dark steel-gray color as the Al_2O_3 is increased.

Alumina replacing the iron in the silicate has very little effect on the formation temperature until three-eights of the iron is replaced, when the temperature increases suddenly. The slags formed are quite fluid. They are opaque, with a dull luster and a dull, reddish-brown color.

Alumina replacing the lime in the silicate produces a slight reduction in the formation temperature until about six-eighths of the lime is replaced, when the temperature gradually increases a small amount. The slags formed are not fluid, but have a tendency toward viscosity, especially with the higher percentages of Al_2O_3. They are opaque, slightly vitreous in luster, and grayish-black to black in color.

Iron.—Iron as a flux for silica alone reduces the fusing temperature of the silica only slightly. Iron in the presence of lime tends to make the slag readily fusible and fluid. U. S. Geological Survey boiler tests show that as the per cent. of iron in the coal increases, there is a decided increase in the per cent. of clinker in the ash. However, as will be seen further along, iron may be present in a coal in considerable quantities and yet not cause clinker.

Lime.—Lime replaced with MgO causes a de-

cided rise in the formation temperature, especially when more than half the lime has been replaced. The MgO reduces the fluidity of the slag, which has a vitreous luster and is of a brownish color.

CLINKER CALCULATIONS

In a paper delivered before the Coal Mining Institute of America, in 1912, Mr. E. B. Wilson, Editor of Mines and Minerals, presented a paper on "Clinkering of Coal Ashes," in which he advocated the use of Balling's factors in order to calculate whether, from the per cent. of silica and oxides present in an ash, they were in proper proportions for the coal to clinker in burning. The method consists in calculating the amount of silica necessary to reduce the basic oxides of the ash to a monosilicate, a monosilicate being a silicate in which the oxygen in the basic oxides is equal to that in the silica. The method of calculation is as follows: Calcium monosilicate is formed by the combination of lime with silica after the reaction, $2CaO + SiO_2 = 2CaO.SiO_2$. The molecular weights are, $112.14 + 60.03 = 172.17$. Dividing the molecular weight of the acid, 60.03, by that of the base, we have, $60.03 \div 112.14 = .535$. This is known as Balling's factor for lime, and it means that .535 part of silica is required to 1 part of lime in order to form 1.535 parts of calcium monosilicate. The same method is followed in finding the factors for the other bases, and they are as follows: CaO, .535; Al_2O_3, .885; FeO, .418; and MgO, 747.

The following analyses of two coals, with their ash analyses will be used to illustrate the method of slag calculations.

	West Virginia Coal.	Alabama Coal.
Analyses of coal:		
Moisture	.496	1.59
Volatile	19.139	30.15
Fixed Carbon	75.53	50.39
Ash	6.36	15.33
Sulphur	.48	2.54
Analyses of ash:		
SiO_2	39.02	29.14
Al_2O_3	23.52	15.56
CaO	19.97	20.73
MgO	3.27	11.91
FeO	11.14	13.42
S	.24	6.00
Undetermined	2.84	....

SILICA REQUIRED TO FORM MONOSILICATES

	West Virginia Coal.			Alabama Coal.		
Basic Oxide.	Per Cent.	Factor.	Silica Required.	Per Cent.	Factor	Silica Required.
Al_2O_3	23.52 x	.886 =	20.815	15.56 x	.885 =	13.776
FeO	10.60 x	.418 =	4.443	00.00 x	.418 =	00.000
CaO	19.97 x	.535 =	10.684	20.73 x	.535 =	11.091
MgO	3.27 x	.747 =	2.443	1.91 x	.757 =	1.446

SiO_2 required by basic oxides	38.385	26,313
SiO_2 in coal................	39.020	29.140
SiO_2 in excess.............	.637	2.827

It will be seen that the right proportion of silica is present in each coal to slag all the oxides and form monosilicates. However, this does not signify that both coals will clinker with equal ease when burned in a furnace. The Alabama coal will require a very much higher temperature than the Virginia coal before clinker will form, owing to the fact that there is an absence of available iron in that coal. The slagging temperatures of alumina, lime, and mag-

nesia are so high that, unless sufficient available iron is present, no monosilicate would be formed under ordinary furnace conditions. The Alabama coal may therefore be considered a non-clinkering coal on account of the absence of available iron, the magnesium content, and the percentage of lime present.

If there is 10 per cent. or more of available iron in the ash of a coal in which there are proportions of other bases and silica present to form monosilicates, as in the case of the Virginia coal, a fluid slag will form and at a comparatively low temperature. The Virginia coal, therefore, will cause troublesome clinker, on account of the percentage of available iron and of lime it contains, both tending to reduce its fusing temperature. With the increase of available iron in the ash above 10 per cent., the slagging temperature decreases considerably. With 5 per cent. or less available iron in the ash, the percentage, as compared with the more refractory bases, is so small that only a little slag would form, and this at very high temperatures; hence, little trouble would be experienced at ordinary furnace temperature from such an ash.

Available Iron.—Iron to be available for slagging must be in the form of iron oxide, either as FeO or as Fe_2O_3. Silica will not combine with iron when the iron is in the form of ferrous sulphide, FeS. Therefore, if there is sufficient sulphur in the coal to combine with all the iron, no iron will be available for a ferrous monosilicate.

The Virginia coal contained .48 per cent. of sulphur, half of which burned and the other half, .24 per cent., combined with the iron of the coal. Therefore, while the ash contained 11.14 per cent. of FeO,

only 10.6 per cent. was available in forming mono-silicates. In the Alabama coal, no available iron was present in the ash, because there was just sufficient sulphur present in the coal to combine with all the iron, as will be seen from the following calculation:

Ferrous oxide contains $\dfrac{56 \times 100}{72} = 77.7$ per cent. of iron. The 13.42 per cent. of ferrous oxide in the Alabama coal ash contained $13.42 \times .777 = 10.44$ per cent. of iron. The iron necessary to satisfy the 6 per cent. of sulphur in that ash is $\dfrac{55.84 \times 6}{32.07} = 10.45$ per cent., so that no iron was available in the ash.

Effect of Sulphur.—Sulphur is not a slag-forming material; on the contrary, it often prevents the formation of clinker by reducing the amount of available iron present in the ash. However, under certain conditions, sulphur in the coal may exert considerable influence on the tendency of the ash to clinker. It generally occurs either in the form of pyrites or as calcium sulphate, the pyrites occurring in much larger proportions than the sulphate and being more troublesome on account of the tendency of its iron to form clinker. The tendency to produce clinker depends on the percentage of sulphur in the ash, rather than on the percentage of sulphur in the coal. A coal with a high-sulphur content commonly has a high-ash content. The percentage of sulphur in the ash, therefore, is low, and the sulphur may not prove very troublesome, because under such conditions, the temperature of the fuel bed is apt to be low. When the percentage of sulphur to ash is high, especially in low-ash coals, a very troublesome clinker usually results. Ferrous sulphide melts at 2,138° F.;

therefore, if the fuel bed temperature is greater than this, the FeS will melt and run through the surrounding ash. As the molten FeS cools, it cements a mass of coal and ash together into a hard clinker. The clinker thus formed shuts off the supply of air through the grates underneath it. The clinker and the grate bars underneath it then become overheated, the grate bars warp, and the clinker melts and runs into the spaces between the grate bars. The sulphur of the clinker then combines with the metal of the grate bars, and a wasting of the grate results. The combined warping and wasting thus produced results in the destruction of the grates in a comparatively short time.

Fusing Temperature of Ash.—While it is possible by the methods just explained to determine from a chemical analysis of a coal whether the ash will slag or not, provided the proper temperature is obtained, yet it is not always possible to say whether the coal will clinker under the conditions of a given furnace. The conditions in one furnace may be such that a coal will not clinker badly, whereas, in another furnace, the same coal may give considerable trouble. The surest method of determining whether a coal will clinker is to try it out in the furnace in which it is to be burned. If this is not practicable, the melting temperature of the ash may be determined experimentally by means of seger cones as follows:

Moisten the powdered ash with a 10-per-cent. solution of dextrine, work it into a stiff paste, and mold it into pyramids of the standard form and dimensions of a seger cone. Select several seger cones that will give you the desired range of temperature, both below and above the probable formation temperature of the ash slag, and slowly heat the

seger cones and the ash cones in a gas muffler or some other heater. Raise the temperature slowly, at a rate of about 2° C. or 3.6° F. per minute, as the rate of rise of the temperature has considerable effect on the melting temperature of the cones. Compare the seger cones at the instant when the ash cones melt, or fuse; the temperature represented by the seger cone that is bent nearest the standard final form should be taken as the formation, or fusing, temperature of the ash.

Seger Cones.—Seger cones are valuable as a means of finding the fusing temperature of ashes, because the ash cones and the seger cones are exposed to the same temperature. In order to insure success, the cones must be heated at the rate of temperature, 2° C. per minute, and the Seger cones taken as indicating the temperature must be the one bent nearest to the standard final form. The ash cones must be of the same size and form as the seger cones.

Seger cones are three-sided pyramids. Nos. 22 to 25 are 3 inches high and have a base ⅝ inch wide; Nos. 26 to 36 are 25/32 inch high and have a base ⅜ inch wide; see Table XII. The number of each cone will be found on its side.

Several seger cones representing the desired range in temperature are placed in the furnace with the ash cones, and the temperature of the furnace corresponds to that of the seger cone, the top of which has bent over and touched a horizontal line, called the base, as the ash cone fuses. The seger cone with the lowest number always melts down first, the others following in their respective orders, according to their number.

TABLE XII.
Seger Cones.

No. of Cone	Composition			Melting-Point	
				°F.	°C.
022	0.5 Na_2O / 0.5 PbO	· · · · · · · · · · · ·	2.0 SiO_2 / 1.0 B_2O_3	1,094	590
021	0.5 Na_2O / 0.5 PbO	0.10 Al_2O_3	2.2 SiO_2 / 1.0 B_2O_3	1,148	620
020	0.5 Na_2O / 0.5 PbO	0.20 Al_2O_3	2.4 SiO_2 / 1.0 B_2O_3	1,202	650
019	0.5 Na_2O / 0.5 PbO	0.30 Al_2O_3	2.6 SiO_2 / 1.0 B_2O_3	1,256	680
018	0.5 Na_2O / 0.5 PbO	0.40 Al_2O_3	2.8 SiO_2 / 1.0 B_2O_3	1,310	710
017	0.5 Na_2O / 0.5 PbO	0.50 Al_2O_3	3.0 SiO_2 / 1.0 B_2O_3	1,364	740
016	0.5 Na_2O / 0.5 PbO	0.55 Al_2O_3	3.1 SiO_2 / 1.0 B_2O_3	1,418	770
015	0.5 Na_2O / 0.5 PbO	0.60 Al_2O_3	3.2 SiO_2 / 1.0 B_2O_3	1,472	800
014	0.5 Na_2O / 0.5 PbO	0.65 Al_2O_3	3.3 SiO_2 / 1.0 B_2O_3	1,526	830
013	0.5 Na_2O / 0.5 PbO	0.70 Al_2O_3	3.4 SiO_2 / 1.0 B_2O_3	1,580	860
012	0.5 Na_2O / 0.5 PbO	0.75 Al_2O_3	3.5 SiO_2 / 1.0 B_2O_3	1,634	890
011	0.5 Na_2O / 0.5 PbO	0.80 Al_2O_3	3.6 SiO_2 / 1.0 B_2O_3	1,688	920
010	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.50 SiO_2 / 0.50 B_2O_3	1,742	950
09	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.55 SiO_2 / 0.45 B_2O_3	1,778	970
08	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.60 SiO_2 / 0.40 B_2O_3	1,814	990
07	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.65 SiO_2 / 0.35 B_2O_3	1,850	1,010
06	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.70 SiO_2 / 0.30 B_2O_3	1,886	1,030
05	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.75 SiO_2 / 0.25 B_2O_3	1,922	1,050
04	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.80 SiO_2 / 0.20 B_2O_3	1,958	1,070
03	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.85 SiO_2 / 0.15 B_2O_3	1,994	1,090
02	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.90 SiO_2 / 0.10 B_2O_3	2,030	1,110
01	0.3 K_2O / 0.7 CaO	0.20 Fe_2O_3 / 0.30 Al_2O_3	3.95 SiO_2 / 0.05 B_2O_3	2,066	1,130

TABLE XII—Continued.

No. of Cone	Composition					Melting-Point	
1	{0.3 K₂O / 0.7 CaO}	0.20 Fe₂O₃ / 0.30 Al₂O₃	4	SiO₂	2,102	1,150	
2	{0.3 K₂O / 0.7 CaO}	0.10 Fe₂O₃ / 0.40 Al₂O₃	4	SiO₂	2,138	1,170	
3	{0.3 K₂O / 0.7 CaO}	0.05 Fe₂O₃ / 0.45 Al₂O₃	4	SiO₂	2,174	1,190	
4	{0.3 K₂O / 0.7 CaO}	0.5 Al₂O₃	4	SiO₂	2,210	1,210	
5	{0.3 K₂O / 0.7 CaO}	0.5 Al₂O₃	5	SiO₂	2,246	1,230	
6	{0.3 K₂O / 0.7 CaO}	0.6 Al₂O₃	6	SiO₂	2,282	1,250	
7	{0.3 K₂O / 0.7 CaO}	0.7 Al₂O₃	7	SiO₂	2,318	1,270	
8	{0.3 K₂O / 0.7 CaO}	0.8 Al₂O₃	8	SiO₂	2,354	1,290	
9	{0.3 K₂O / 0.7 CaO}	0.9 Al₂O₃	9	SiO₂	2,390	1,310	
10	{0.3 K₂O / 0.7 CaO}	1.0 Al₂O₃	10	SiO₂	2,426	1,330	
11	{0.3 K₂O / 0.7 CaO}	1.2 Al₂O₃	12	SiO₂	2,462	1,350	
12	{0.3 K₂O / 0.7 CaO}	1.4 Al₂O₃	14	SiO₂	2,498	1,370	
13	{0.3 K₂O / 0.7 CaO}	1.6 Al₂O₃	16	SiO₂	2,534	1,390	
14	{0.3 K₂O / 0.7 CaO}	1.8 Al₂O₃	18	SiO₂	2,570	1,410	
15	{0.3 K₂O / 0.7 CaO}	2.1 Al₂O₃	21	SiO₂	2,606	1,430	
16	{0.3 K₂O / 0.7 CaO}	2.4 Al₂O₃	24	SiO₂	2,642	1,450	
17	{0.3 K₂O / 0.7 CaO}	2.7 Al₂O₃	27	SiO₂	2,678	1,470	
18	{0.3 K₂O / 0.7 CaO}	3.1 Al₂O₃	31	SiO₂	2,714	1,490	
19	{0.3 K₂O / 0.7 CaO}	3.5 Al₂O₃	35	SiO₂	2,750	1,510	
20	{0.3 K₂O / 0.7 CaO}	3.9 Al₂O₃	39	SiO₂	2,786	1,530	
21	{0.3 K₂O / 0.7 CaO}	4.4 Al₂O₃	44	SiO₂	2,822	1,550	
22	{0.3 K₂O / 0.7 CaO}	4.9 Al₂O₃	49	SiO₂	2,858	1,570	

TABLE XII—Continued.

No. of Cone	Composition					Melting-Point	
						°F.	°C.
23	0.3 K₂O 0.7 CaO	5.4	Al₂O₃	54	SiO₂	2,894	1,590
24	0.3 K₂O 0.7 CaO	6.0	Al₂O₃	60	SiO₂	2,930	1,610
25	0.3 K₂O 0.7 CaO	6.6	Al₂O₃	66	SiO₂	2,966	1,630
26	0.3 K₂O 0.7 CaO	7.2	Al₂O₃	72	SiO₂	3,002	1,650
27	0.3 K₂O 0.7 CaO	20	Al₂O₃	200	SiO₂	3,038	1,670
28	....	1	Al₂O₃	10	SiO₂	3,074	1,690
29	....	1	Al₂O₃	8	SiO₂	3,110	1,710
30	....	1	Al₂O₃	6	SiO₂	3,146	1,730
31	....	1	Al₂O₃	5	SiO₂	3,182	1,750
32	....	1	Al₂O₃	4	SiO₂	3,218	1,770
33	....	1	Al₂O₃	3	SiO₂	3,254	1,790
34	....	1	Al₂O₃	2.5	SiO₂	3,290	1,810
35	....	1	Al₂O₃	2	SiO₂	3,326	1,830
36	....	1	Al₂O₃	1.5	SiO₂	3,362	1,850

NOTE.—Table by Prof. H. O. Hofman, T. A. T. M. E., Vol. 29.

Hard Clinkers.—Two distinct kinds of clinkers are formed in furnace combustion, one known as soft clinker and the other as hard clinker.

Soft clinker is formed by the slagging of the ash. It is not directly chargeable to bad methods of firing, although under some conditions poor firing may be the cause of starting the clinker and may hasten its spread. Soft clinker may have a consistency varying from that of a thick paste to that of a

heavy valve oil. The pasty clinker is not so trouble-some as the more fluid clinker, because the more fluid the clinker is the faster will it spread. Also, the very fluid clinker will flow down between the fingers of the grates and into the grate openings and harden, thus blocking the grate bars and shutting off the draft through that portion of the grate. Often it will hang down like icicles from the grate bars and flow into the ashpit.

When first formed, a soft clinker is similar in appearance to that of a hard clinker, but it differs from a hard clinker in that it steadily grows in size, until it finally spreads over practically the whole grate area. Inspection shows that the clinker has a crust on the upper surface, underneath which it is fluid. A soft clinker is formed by the silica of the ash combining with the base that has the lowest fusing temperature. Once formed, the silicate dissolves both the silica and the base and in this way grows in extent. The clinker shuts off the air supply through that part of the grate occupied by it, so that the temperature of the ash at that point is raised to a temperature at which other silicates can form. By the formation of other silicates and by the dissolving of silicates and bases into each other, the fluid slag gradually grows in extent until it eventually covers practically the whole grate surface.

Hard clinker is of two kinds, the hard cake-clinker and the small, hard clinker. The hard cake-clinker is usually the direct result of bad firing methods. The temperature of the ash, which is next to the grate, is considerably cooler than that of the burning coal in the firebed, so that an ash that will not fuse when next to the grate will fuse if raised up into the burning coal of the firebed. Once melted, it

runs downward, is cooled, and hardens, cementing pieces of coal and ash together into a hard, cake-like clinker. Also, if the firebed is stirred up so that fresh coal is worked down onto the grates, the coal in burning will raise the temperature of the ash at that point and very probably will start the formation of soft clinker, provided the ash constituents are in the right proportions, or will fuse some of the ash and produce a hard clinker.

Small, hard clinkers are caused by the fusing of certain ingredients of the ash. Usually, such clinkers do not cause serious trouble.

PREVENTION OF CLINKER

If a coal always clinkers under normal conditions and with a proper method of firing, it may safely be charged to the composition of the ash, on account of which the ash fuses or slags at a temperature below the regular ash-bed temperature. If the coal clinkers only occasionally, then it may be due to impurities that accidentally became mixed with the coal; to the fact that the slagging or the fusing temperature of the ash is only slightly greater than that of the working temperature of the ash-bed, and the ash-bed temperature occasionally rises to the fusing temperature of the ash; or to a wrong method of firing.

Use of Limestone.—Since clinker is due to the ash-bed temperature being higher than the slagging or fusing temperature of the ash, the way in which to overcome clinkering is either to lower the ash-bed temperature or to raise the fusing temperature of the ash. Carrying a thin fire and admitting an excess of air through the grates has often been

found effective for reducing the temperature of the ash sufficiently to prevent clinker. The excess air causes a loss in efficiency, but the loss is less than if bad clinker forms.

The slagging temperature of the ash may be raised by spreading crushed limestone or broken oyster shells over the thin, clean firebed on starting, the added ingredients making the ash material more refractory. The idea is to add enough lime to the ash to bring its fusing temperature on that part of the curve, Fig. 7, to the right of the point a, so that the ash will have a sufficiently high formation temperature to prevent slagging. This method, however, is hardly suitable for every-day use, unless under conditions where a very bad coal must be used.

Use of Water Vapor.—With high-ash coals that clinker because of the presence of ferrous sulphide, the clinker can often be prevented by keeping the ash-pit doors wide open and this pit clean, so as to reduce the ash-pit temperature, regulating the draft by the uptake damper. Keeping a supply of water in the pit will prove effective also. If the clinker is very fluid and freezes to the grates, the use of steam jets below the grates may not prevent the formation of clinker, but it will prevent the clinker from freezing to the grates.

The action of water in the ash-pit is the same as the action of the steam jets, only less in amount, since there is less vapor to do the work. Water vapor begins to dissociate when heated to a temperature of about 1,800° F., and is half dissociated at about 4,500° F. On cooling, the mixed gases recombine. In order to decompose water by heat, as much heat must be absorbed by the water as was evolved when the water was formed. From Table XVIII, 1 pound

of hydrogen combining with 8 pounds of oxygen forms 9 pounds of water vapor, and, Table XVII, evolves 62,000 B. T. U. of heat. In forming 1 pound of water about 6,900 B. T. U. are evolved. Each pound of water dissociated, therefore, must absorb 6,900 B. T. U. of heat.

The action of water vapor in reducing or preventing the formation of clinker, is as follows: The vapor in passing up through the grates and ash absorbs heat and is dissociated. This lowers the temperature of the grates and the ash, and so reduces, and, in some cases, prevents the slagging of the ash. In bad cases of clinkering with high-ash coals, this treatment may not always prevent clinkering, but it will prevent the clinker from adhering to the grate bars, thereby making the cleaning of the fire much easier.

Care in Use of Rake, Slice Bar, and Shaker.— If pyrite, FeS_2, is heated to a low-red heat in an insufficient supply of air, as would be the case of high-ash coal in a firebed so thick as to restrict the air supply, 1 molecule of the sulphur of the pyrite will be driven off, forming SO_2 gas and reducing the pyrite to ferrous sulphide, FeS. The sulphur in the ferrous sulphide will not combine with oxygen at temperatures as low as that of the ash-bed in a furnace; hence, the iron of the sulphate will not combine with the silica of the ash to form a fusible slag. However, ferrous sulphide often is the cause of very troublesome, hard clinkers. It melts at a temperature of 2,138° F. and attaches itself to surrounded coal and ash and forms them into a hard mass or clinker that is very troublesome. The remedy for this type of clinker is to carry a thin, clean fire, so as to insure plenty of excess air, and to avoid

mixing the ash with the incandescent coal in the fire-bed. Care in the use of the rake, the slice bar, and the grate shaker will avoid the formation of hard clinkers. Stirring the fire comes next to carrying too thick a fire as the most frequent cause of trouble-some clinker, especially if the fire is broken by means of the slice bar. Running the slice bar under the fuel bed and then prying it up to break a clinker or a coke crust, is a sure method of causing hard clinkers to form. Also, lifting ash up into the hot zone of the fire by the improper use of the rake is a frequent cause of hard clinker. Shaking the grate hard enough to work coal down on the grate will surely cause clinkers. Mixing two coals will sometimes cause clinkers, even though neither of the coals clinker when burned separately.

Summary.—Briefly, then, to prevent clinker:

Carry a thin, level fire.

Use care in shaking the grates.

Avoid the use of the slice bar and the rake.

Fire in small quantities on the thin spots of the fire.

Avoid the formation of banks.

Take especial care in firing slack coal to fire small quantities at a time, so as to avoid coking a thick crust.

Keep the ash-pit doors wide open and the ash pit clean.

If necessary, keep water in the pit, or use steam jets to prevent clinker from sticking to the grates.

Avoid shaking coal that will burn into the ash pit.

In handling coal, avoid all chance of mixing foreign impurities with it.

Removing Clinkers.—The only way in which to remove soft clinker is to clean the entire furnace and build a new fire. Once a soft clinker starts to form, it generally is only a question of time when it will result in an engine failure or a shut-down.

In the case of a hard, cake clinker, it can sometimes be broken up by shaking the grates with short, quick jerks. Generally, however, the fire must be cleaned and the clinker broken up and dropped through the door. In some cases, it may be possible to turn the clinker up on edge or to pull it out on top of the firebed and allow the fire to disentegrate it, but this method is very apt to start the formation of new clinkers.

Disadvantages of Clinkers.—In bad cases of clinkering, the clinker decreases both the furnace efficiency and the furnace capacity. It increases both the labor and the cost of firing, shortens the life of the grates and the firebrick lining of the furnace, and, in extreme cases, may cause the power plant to be shut down because of the grates becoming clogged.

CHAPTER VII

GEOLOGICAL HISTORY OF COAL

GENERAL PRINCIPLES. — In order to have a thorough working knowledge of American coals, one must be familiar not only with the nature and the properties of the different classes of coals, but also with the geology of coal, and with the location and the characteristics of the several coal fields of America. The study of the nature and properties of coal has just been completed; the geology, location, and characteristics of the coal fields will now be treated briefly.

The word geology is from two Greek words signifying "the story of the earth." Geology is the science that treats of the past conditions of the earth and of its inhabitants. It is concerned chiefly about the evolution of the earth's features from former conditions, and about the previous forms and the distribution of animals and plants. The science of geology is based on the fact that nature has written its own history in the rock formations that have gradually accumulated throughout the past ages. The crust of the earth is estimated to be about 30 miles thick, and the lower strata of rocks form the first pages in the history of time.

In writing this history, nature has made use of the rock formations of the different ages for the pages of her book, and has used the fossils of the faunas and floras of each age as the type wherewith to print the history. The rocks of the bygone ages were formed in water by the settling of sediment, so

that where no great disturbance has taken place the relative positions of the rock strata indicate the relative ages of the strata, the uppermost, of course, being the youngest. However, all the strata are not represented in any one place, and, usually, only a few are represented, so that the age of the rocks cannot always be determined from the order of their superposition. Hence, the age to which the rock formations belong must be determined by a careful comparison of the character of the rock and the character of the fossils in different localities with one another. To be of the same age, both the rock and the fossils of different localities must be generally similar.

In the early ages, the first forms of life of which there is any record were very low. These were followed by others of higher form of life, and these by others of still higher form, and so on through age after age until the appearance of man. Each change in the form of life to a higher form invariably was preceded by changes in the physical conditions of the earth and in the atmosphere, that made living possible to the higher form of organism. Each of these great changes in the physical conditions, therefore, marks an era in the history of the earth. Each era is distinguished from the others by the fossils of the particular forms of life that were dominant during that era. The plants and animals that lived left relics in the form of leaves, shells, bones, teeth, corals, etc. in the mud, sand, and other deposits as a record of their existence; consequently, wherever a rock formation is found, the fossils that it contains proclaim the era to which it belongs.

Geologists have divided and subdivided the limits of the divisions of the rocks, and the correspond-

ing divisions of time, into eras, ages, periods and epochs, as determined by great changes in physical geography, climate, and forms of organisms. These divisions of time are recorded in separate systems, rock series, and rock formations, according to their importance. The eras, ages, periods, etc. usually graduate into each other; yet there are times of revolution in which the steps of change are far more rapid than ordinarily. Thus, geological history, like human history, consists of periods of comparative quiet and prosperity and of periods of revolution.

Just as in human history, which marks the several ages of man in accordance with some dominant characteristic, social force, or principle, as the stone age, the age of chivalry, the age of reason, etc., so, also, in geological history, what is designated as an age is marked by the dominance of some particular class of animals or plants. Thus, there is an age of mollusks, the age of fishes, the age of reptiles, etc., in which each class is successively the dominant type for its age. Each dominant type culminates and then declines and becomes subordinate to the next incoming and higher order of life. Thus, the organic kingdom steadily becomes of higher and higher form of life, and of more complex structure as a whole, as shown in the accompanying schedule of the divisions of the rocks and the corresponding divisions of time, Table XIII.

Divisions of Geological History. — From the schedule of the division of the history of the earth and the rocks, it will be seen that there are five primary divisions called eras, each embodied in a corresponding system of rocks. The time covered by the five eras is subdivided into seven divisions, called ages, each Age being characterized by a dominant

TABLE XIII.

Schedule of the Limits of the Divisions of the Rocks and Corresponding Divisions of Geological Time.

Eras.	Ages.	Periods.	Epochs.
5. Psychozic (Rational Life)	7. Age of Man........	Human Present Sediments— Peat Beds..........	Recent
4. Cenozoic (Recent Life) ..	6. Age of Mammals...	Quaternary Rocks..... Tertiary Rocks........	Terrace Champlain Glacial Piocene Miocene—coal lignite Eocene
3. Mesozoic (Middle Life) ...	Secondary Rocks ...... 5. Age of Reptiles.....	Cretaceous Rocks—Coal Jurassic —Coal Triassic —Coal Permian Rocks	
Upper	Carboniferous Rocks .. 4. Age of Acrogene (Acrogen Plants) and Amphibians (Reptiles capable of living in both air and water)..... Devonian Rocks	Carboniferous Rocks— Coal Measures Subcarboniferous Rocks Catskill Chemung	

TABLE XIII—Continued.

Eras.	Ages.	Periods.	Epochs.
2. Paleozoic (Old Life)	3. Age of Fishes......	Hamilton Corniferous Oriskany Helderberg Salina Niagara Trenton Canadian	
	Silurian Rocks		
Lower	2. Age of Invertebrates (Mollusks — Animals similar to the oyster, clam snail and cuttlefish; some with shell, and some without)		
	Cambrian or Primordial Rocks	Upper Middle Lower	
	1. Archæan Age	Huronian	
1. Archæozoic (Primeval Animal Life)	Archean Rocks	Laurentian	

class of animals or plants and by their corresponding rocks.

The subdivision of the ages into periods, and the further subdivision of the periods into epochs are made necessary, because, as time comes toward the present, events multiply rapidly and call for closer subdivisions in order that their relations toward each other may be properly fixed.

It is with the periods that the student of the coal field is interested, because the periods indicate the rock formations in which the coal measures occur.

Coal-Forming Periods.—There were three periods of greatest deposit of coal—the carboniferous, the cretaceous, and the tertiary. The carboniferous, or carbonic era, as it is often called, was the time when the most extensive coal beds were formed, fully nine-tenths of the coal being formed during that period. It is called the true coal period, or that of the Coal Measures, the name carbonic being from the latin **carbo,** meaning coal.

The Coal-Measures.—The atmosphere of the carboniferous, or coal-forming, periods was very moist and was composed largely of carbon dioxide, which furnished abundant plant food and contributed largely to the heat. The conditions for the growth of plant life during this period were so favorable that vegetation grew in great profusion. It consisted of the acrogen plants (upward growers) such as tree ferns, lycopods, equiseta, etc., and of the Phænogams, or flowering plants, gymnosperms, or trees of the pine and cycad species. These grew luxuriantly in great forests over the vast marshes, and the coal was formed on the spot where the forest grew. In some special instances, however,

evidence seems to indicate that isolated bodies of coal were formed from vegetable matter that had drifted together in large quantities into lakes and became submerged.

The vegetation formed coal only when it was submerged in low lands or in lakes, and where the deposits of vegetation afterwards became covered with deposits of rock-forming material. The more continuously the vegetation was submerged, the more thoroughly the coal formation from it was bituminized; the immersion in water contributing greatly to the formation of the more highly bituminous coals.

The coal fields, or coal measures, as they are called, consist of a number of beds of coal separated by strata or rock consisting of slates, shales, sandstone, or limestone deposits, which exerted different degrees of pressure on the coal under formation and assisted in the subsequent crystallization of the coal. The depth of the coal measures ranges from 2,000 to 15,000 feet, with the number of seams of coal ranging from a few to a hundred or more. The coal beds, or seams, vary in thickness from less than an inch to 60 feet. The relative thickness of the coal beds to the rock strata between the beds is not more than 1 foot of coal to 50 feet of rock in the best coal measures.

The bed, or seam, of coal that is less than 18 inches thick is unworkable. Such a seam is said to be barren. Barren measures are coal measures without workable seams. Measures with workable seams are called productive measures.

Devolatilization of Coal.—Geologists now quite generally agree that coal is transformed peat. They differ widely, however, as to just how the trans-

formation of peat to the different kinds of coal is effected. Some of the theories advanced to explain how devolatilization, or carbonization, is brought about claim that it is due to: Differences in the kinds of vegetation from which the coal is formed; climate differences in the regions in which the coal was formed; differences in lapse of time since deposition; enrichment by addition of bitumen from outside sources; differences in depth of burial; changes due to chemical reagents in the subterranean circulation; heat effects of intrusive rocks; porosity of material overlying the coal; escape of volatile matter through joints in the coal and overlying rocks; etc.

The most probable theory, however, is that of Mr. David White, who claims that coal is formed by two processes—the biochemical, or peat-forming, process and the dynamochemical, or devolatilization, process.

Biochemical Process.—Under the biochemical process, the accumulated vegetable matter in the peat bed is disintegrated or decomposed and reduced, and many of the organic chemical compounds of the peat material are changed or broken down under the influence of, or in connection with, the vital activities of microorganisms, the most important of which are bacteria. This process, being dependent on microorganisms, ends when the anaerobic microbes become exterminated through exhaustion of the oxygen necessary for their life, or through the development of toxis. The extent to which the process progresses, therefore, depends on the conditions of deposition and on the nature of the material deposited. The process may be cut short, as is indicated by wood and fibrous material in the case of certain lignites, and of woody or fibrous peat;

or, it may progress far enough nearly to obliterate the nature of the peat materials, as in the case of so-called amorphous coal and peat. When the bio-chemical process has ceased in the early stages of decay of the plant material, it results in a light-brown, fibrous, or woody, peat. If the process has progressed farther, it results in a more mature peat that is less woody, or fibrous, and is of a darker brown. At a more advanced stage, the peat is black, and the plant matter is nearly all decayed. The color of the peat, therefore, is an indication of the extent of the biochemical action.

Dynamochemical Process.—The dynamochemic-al process follows the biochemical process, and com-prises the chemical and physical alterations of the peat, induced and controlled by geodynamic influ-ences. As the weight of the overlying strata in-creased, it compressed the coal-forming material, pressing out some of the water and gases and con-solidating the peat into a more compact mass. The liquid putrefaction products partly hardened and formed the binder for the mass. As the process pro-ceeded, additional changes in the chemical constitu-tion occurred, and the plant constituents not pre-viously affected were decomposed and some of the organic matter was driven off in the form of gases and water. The chemical changes taking place were indicated by the progressive loss of volatile matter, as is seen in the different kinds of coal from the sub-bituminous to the anthracite.

Besides the vertical pressure that the coal was subjected to, due to the weight of the overlying strata, it was subjected to a horizontal thrust pres-sure, which was even more effective than the vertical pressure in devolatilizing and concentrating the coal.

The stage of devolatilization depends both on the intensity and on the duration of the pressure to which the coal was subjected; that is, the changes produced by a moderate pressure for a long period would be produced in a shorter period by more intense pressure. Also, according to the theory of the dynamochemical process, the chemical changes resulting in the loss of volatile matter took place under relatively low temperatures, although intense heat at any point would greatly accelerate the change.

Cannel Coal Formation.—Cannel coals differ from bituminous coal not so much in their ingredients as in the proportions of the ingredients and their state of metamorphism. For instance, typical cannel coal is compsoed chiefly of spore exines, with a very little cuticular material derived from woody constituents. Typical bituminous coal is composed chiefly of woody constituents, although it contains varying amounts of spore exines, cuticles, resins, waxes, etc. However, there is no sharp distinction between cannel and other grades of coal, because between the typical cannel and the typical bituminous coals there are gradual transitions from one to the other. The typical cannel peat bed differs from the ordinary peat bed in that it was formed at the bottom of open lakes of suitable depth, rather than in marshes and in swamps. These lakes were surrounded by forests, the trees of which, year after year, shed their spores into the waters. These spores formed a bed of sporiferous material on the bottom of the lake and thus formed the material for the peat bed. The beds, therefore, contained but very little woody material. Except for the difference in the material of the peat beds, the process of coal formation was the same for all coals.

WASHINGTON FIELDS

OREGON

MONTANA

N. DAKOTA

S. DAKOTA

IDAHO

WYOMING FIELDS

MOUNTAIN FIELDS

NEBRASKA

PACIFIC COAST

CALIFORNIA

NEVADA

UTAH

ROCKY MOUNTAIN

COLORADO

KANSAS

PACIFIC OCEAN

ARIZONA

NEW MEXICO

OKLA

SOUTH

TE

MEXICO

C A

COAL FIELDS OF

The map shows the eastern United States with labeled regions including:

CANADA

MINNESOTA, WISCONSIN, MICHIGAN, IOWA, INDIANA, OHIO, PENNA, MISSOURI, TENN., ARKANSAS, MISSISSIPPI, LOUISIANA, GEORGIA, NORTH CAROLINA, SOUTH CAROLINA, VIRGINIA, MARYLAND, NEW YORK, MAINE, VT., N.H., MASS., CONN., N.J., ALABAMA, FLORIDA

MAINE GRAPHITE FIELD

NORTHERN INTERIOR, EASTERN INTERIOR, WESTERN INTERIOR, NORTHERN APPALACHIAN, SOUTHERN APPALACHIAN, ATLANTIC COAST TRIASSIC

GULF

ATLANTIC OCEAN

GULF OF MEXICO

CHAPTER VIII

GRAPHITE FIELDS.—For convenience in classifying the coals of the country, the coal areas of the United States have been divided by U. S. geologists into ten fields. The location of these coal fields and the character and geological age of the coal of the several fields are indicated on the accompanying map of the coal fields of the United States. The map shows also the graphite fields of Rhode Island. The mines of the Rhode Island fields were once worked as anthracite mines, but the product is now classed as graphite and is no longer mined for fuel purposes.

Pennsylvania Anthracite Fields.—The coal from the Pennsylvania anthracite fields is found in the regular carboniferous measures. It is a pure, glassy-black anthracite, the seams of coal in the mines varying from 3 to 60 feet in thickness. It is low in moisture and in volatile, high in fixed carbon, and low in ash. It contains only about .65 per cent. of sulphur. The volatile is mostly vapor of the moisture of the coal, so that it gives off but very little combustible gas. The anthracite is confined almost exclusively to Northern Pennsylvania, underlying an area of about 480 square miles, including the counties of Susquehanna, Lackawanna, Luzerne, Carbon, Schuylkill, Columbia, Northumberland, Dauphin, and Sullivan.

In two small areas, one in Gunnison County,

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Colo., and the other in Santa Fé County, N. M., the coal has been locally anthracited. The coal from these localities is a true anthracite of good quality, but of limited quantity, the output having never reached 100,000 tons in any one year.

Atlantic Coast Triassic Fields.—It will be seen from the map that the fields of the Atlantic Coast are of the triassic period and are entirely detached from the fields of the carboniferous period. They aggregate about 660 square miles and are situated midway between the coast and the Blue Ridge mountain range. The fields embrace the Farmville basins of Virginia, and the Dan River, and the Deep River basins of North Carolina. The coal is chiefly bituminous and of a caking nature, although a small amount of semibituminous coal is mined. The beds of all three fields are of moderate thickness and are much disturbed by flexures and faults.

The moisture in the coal varies from .36 to 1.66 per cent.; the volatile from 10 to 34.25 per cent.; the fixed carbon from 53.6 to 80.3 per cent.; the ash from 3.24 to 26.16 per cent.; and the sulphur from 1.93 to 5.56 per cent.

Appalachian Fields.—The Appalachian fields are of the true carboniferous period, and derive their name from the fact that they lie along the western side of the Appalachian Mountains. They are the largest and richest fields in the world, being over 800 miles long, from 30 to 80 miles wide, and underlying 59,370 square miles. The coal measures vary from a few hundred feet to 4,000 feet in thickness.

The coal beds are in two groups, the upper and the lower. The upper barren measures in some places are more than 1,000 feet thick, while the upper pro-

ductive measures are 360 feet thick. The lower productive measures are 280 feet thick, while the lower barren measures are 600 feet thick.

The coal is mostly bituminous, although considerable semibituminous coal is mined. The beds vary in thickness from a few inches to 10 feet. About one-seventh of the coal mined is caking coal. The percentage of coal to intervening rock is about 1 foot of coal to 50 feet of rock.

The coal is low in moisture, varying from 1.5 to 1.8 per cent.; the volatile, from 19.81 to 41.86 per cent.; the fixed carbon, from 53.37 to 72.71 per cent.; the ash, from 4.82 to 10.52 per cent.; and the sulphur, from .65 to 2.64 per cent.

Northern Interior Fields.—The coal of the Northern interior fields is bituminous, and of the true carboniferous period. The geological formations have not been studied extensively, but the coal measures are overlaid with deep glacial drift, which rests on an irregular surface of carboniferous rocks. The drift contains much water and many large boulders, which makes the work of shaft sinking very difficult. The field lies entirely within the state of Michigan, and underlies an area of 7,500 square miles. The coal basin lies in a flat country surrounded by highlands, and the coal seams are irregular in character and in continuity. The coal measures are from 600 to 700 feet thick at the center of the basin.

The coal is high in moisture, ranging from 5.58 to 11.60 per cent.; high in volatile, ranging from 33.14 to 46.73 per cent.; low in fixed carbon, ranging from 45.5 to 53.95 per cent.; fairly low in ash, ranging from 2.41 to 11.68 per cent.; and rather high in sulphur, ranging from 1.1 to 3.83 per cent. Also, the

coal is low in heat units, averaging only about 11,625
B. T. U. per pound.

Eastern Interior Fields.—The Eastern interior
coal fields have not been studied in detail; conse-
quently, the geological structure of the field is but
little understood. The coal is of the carboniferous
period, and varies greatly in different parts of the
field.

The *Illinois coal measures* are divided into the
upper barren measures of fifteen seams, and the low-
er productive measures of seven seams.   The five
principal productive seams are numbered in the
order of their tonnage as follows: Seams numbers
6, 5, 7, 2, and 1. The coal is bituminous, seam num-
ber 3 coming under group H, Table IV, and seams
numbers 6, 1, and 4, under Group I. It is high in
moisture, ranging from 4.5 to 17 per cent.; fairly
high in volatile, ranging from 26 to 33 per cent.; low
in fixed carbon, ranging from 37 to 54 per cent.;
high in ash, ranging from 8 to 16 per cent.; and high
in sulphur, ranging from 3.6 to 5.47 per cent. The
heat value of the coal ranges from 9,500 to 12,700
B. T. U. per pound.

The *Indiana coal measures* comprise sixteen
seams that have been classified in the state coal sur-
vey. All the shipping mines operate in the seams
numbered as follows, in the regular order of their
productiveness: Seams numbers VI, V, IV, III, VII,
and II.   The seams are numbered in the Roman
numerals.   The coal in seams VI, and VII, and in
part of seam V, is bituminous; that in seams II, and
III, and in part of seam IV, is semiblock; the coal in
seam II, is classed in group I, Table IV; while the
coal from seams III and IV is semibituminous.

In seams I to IV, inclusive, the moisture varies

from 3.58 to 8.66 per cent., the volatile, from 32.96 to 39.86 per cent.; the fixed carbon, from 42.67 to 47.41 per cent.; the ash, from 8.6 to 17.08 per cent.; and the sulphur, from 2.58 to 5.24 per cent. The heat value varies from 10,960 to 11,567 B. T. U. per pound.

For the bituminous coals of seams V, to VII, inclusive, the moisture varies from 2.76 to 8.20 per cent.; the volatile, from 38.42 to 40.46 per cent.; the fixed carbon, from 44.65 to 46.55 per cent.; the ash, from 10.23 to 11.72 per cent.; and the sulphur, from 4.14 to 4.6 per cent. The heat units vary from 11,480 to 12,630 B. T. U. per pound.

In the *Kentucky coal measures* as many as twenty seams are recognized geologically. However, mining is confined almost exclusively to seam number 9, or seam C, as it is sometimes called.

The coal is bituminous, with moisture, 6.8 per cent.; volatile, 34.20 per cent.; fixed carbon, 47.25 per cent.; ash, 11.75 per cent.; and sulphur, 5.25 per cent. The heat units are 12,200 B. T. U. per pound. The carbon-hydrogen ratio of this coal places it at the bottom of group H, Table IV.

Western Interior Fields.—The Western interior fields embrace Iowa and Missouri, and consist of two divisions of the coal measures—the upper measures, termed the Missourian division, and the lower measures, termed the Des Moines divisions. The upper measures include a few very thin beds of coal of great regularity and extent. The lower measures include the bulk of the productive coal beds, from 93 to 98 per cent. of the coal mined coming from them. The coal occurs in narrow channels eroded in the earlier rocks, and the beds are irregular, owing

to original irregularities of the bottom over which the coal has accumulated. In some cases, pockets 70 feet thick are found, but they are of very limited extent.

In the *Iowa coal measures,* the productive area lies in the vicinity of the Des Moines River Valley. The coal is a bituminous, non-caking coal. The coal beds cannot be properly called seams, because they consist chiefly of small, detached, separated basins. For this reason, it is impossible to give detailed analytical values to the coal of the different basins, but the average composition for the state is as follows: Moisture, 10 per cent.; volatile, 31 per cent.; fixed carbon, 40.5 per cent.; ash, 14 per cent.; and sulphur, 4.5 per cent. The heat value is 10,450 B. T. U. per pound.

The *Missouri coal measures* are similar in character and in distribution to the Iowa field, except that the beds are of more continuous seams. The field consists of the upper barren measures of nine seams, the middle productive measures of twelve seams, and the lower barren measures of eight seams. Nearly the entire output comes from the middle productive measures. The coal is a non-caking bituminous, with a small amount of caking coal; the composition of the coal being very irregular. The moisture varies from 1.71 to 2.49 per cent.; the volatile, from 31.17 to 38.79 per cent.; the fixed carbon, from 38.78 to 45.44 per cent.; the ash, from 13.28 to 27.57 per cent.; and the sulphur, from 3.47 to 6.34 per cent. The heat value varies from 9,718 to 12,213 B. T. U. per pound.

The *Kansas coal measures* consist of bituminous non-caking coal, with the exception of a very small percentage of the production, which is caking coal.

The moisture varies from 2 to 3.74 per cent.; the volatile, from 31.87 to 37 per cent.; the fixed carbon, from 46.8 to 50 per cent.; the ash, from 12.63 to 18.27 per cent.; the sulphur, from 4 to 8.33 per cent.; and the heat value, from 11,880 to 12,504 B. T. U. per pound.

The *Arkansas coal measures* consist chiefly of semibituminous coal, with some semianthracite. All the coal is non-caking. The moisture varies from .59 to 1.28 per cent.; the volatile, from 15 to 19.75 per cent.; the fixed carbon, from 67.65 to 75.12 per cent., the ash, from 9.27 to 13.52 per cent., the sulphur, from 1.27 to 2.85 per cent.; and the heat value, from 13,100 to 14,083 B. T. U. per pound.

The *Indian Territory coal meaures*, east, are similar to the Arkansas measures; the measures, west are bituminous, part of which is caking coal. The moisture varies from 1.43 to 3.45 per cent.; the volatile, from 33.25 to 37.45 per cent.; the fixed carbon, from 47.82 to 53.08 per cent.; the ash, from 8.87 to 15.03 per cent.; the sulphur, from 1.25 to 3.67 per cent.; and the heat value, from 12,300 to 13,500 B. T. U. per pound.

The Gulf Coal Fields.—The Gulf coal fields, see the map, are composed of brown lignite coal of the Eocene epoch and the Tertiary period. The coals differ very widely in chemical composition and in quality, and information on this nature must be given for each deposit to be of any value. However, an idea of the character of the coal can be obtained from the following analysis, which is the average of several districts: Moisture, from 9.76 to 13.4 per cent.; volatile, from 36.17 to 42.75 per cent.; fixed carbon, from 29 to 43.65 per cent.; ash, from 9.8 to

14.85 per cent.; sulphur, from .7 to 1.04 per cent.; and heat value, from 9,358 to 10,287 B. T. U. per pound.

Rocky Mountain Fields.—The Rocky Mountain fields are scattered over a large area of the Western mountainous regions — 100,110 square miles — the main body of the coal developed being on the eastern side of the Rocky Mountains. The coal varies greatly, some being formed during the Permian period, and some during the Cretaceous and Jurassic periods. Colorado and New Mexico produce all classes of coals from lignite to anthracite. Idaho and Montana produce bituminous and subbituminous; Utah produces bituminous and subbituminous and a small amount of semibituminous; and Wyoming produces bituminous, subbituminous, and considerable semibituminous.

Some of the seams of coal are quite thick. The coals from Ratan and La Plate, Colo., and from Yellowstone, Mont., are coking coals; that from Belt Mountain, Mont., is semicaking.

Pacific Coast Fields.—It will be seen from the map that the Pacific Coast fields consist of a number of detached fields in the states of Washington, Oregon, California, and Alaska. The coal is of the Eocene epoch and the Tertiary period, and the fields aggregate about 30,000 square miles. Generally, the coal is in the form of lignite, subbituminous, or low-grade bituminous coals. In some regions, however, such as the Bellingham and Skogit River regions, in Washington, a very good grade of bituminous coal is found. There are two anthracite regions—one at the head of the Cowlitz River, in Lewis County, Wash., the other on Glacier Creek, near Mount Baker, in

Whatcom County, Wash. The anthracite, however, is not used at present on account of lack of transportation facilities.

Coal Fields of Canada.—In the Dominion of Canada, the coal deposits lie on the Bay of Fundy, and are known as the Nova Scotia and the New Brunswick fields. The coal is of the Carboniferous period, and is similar in quality to the Eastern Appalachian field of the United States. It is used for coking, for iron manufacture, and for industrial power and domestic-heat purposes. The coal measures are 13,000 feet thick, and the two fields aggregate 18,000 square miles. The moisture content varies from .5 to 1.3 per cent.; the volatile, from 25.61 to 37.5 per cent.; the fixed carbon, 42.4 to 65.57 per cent.; and the ash, from 5.5 to 13.39 per cent.

The *Canadian Eastern Rocky Mountain and Great Plain field* is of the Cretaceous period, and is simply a northward extension of the lignite and brown-coal measures of the Rocky Mountain fields of the United States. The moisture ranges from 4.41 to 20.54 per cent.; the volatile matter, from 33.26 to 40.32 per cent.; the fixed carbon, from 39.61 to 48.27 per cent.; and the ash, from 5.05 to 15.64 per cent.

Coal Fields of Mexico.—The coal of the Mexican fields is probably of the Cretaceous or Tertiary periods and appears to be related to the Texas coal of the United States. A fairly good quality of coke is made from the washed coal, provided the coal is properly prepared for the coke oven. The moisture averages about 20.35 per cent.; the volatile matter, about 20.35 per cent.; the fixed carbon, about 46.43

per cent.; the ash, about 12.01 per cent.; and the sulphur, about .86 per cent.

Conclusion.—The study of the coals of America have now been completed, but the subject cannot be dropped without again pointing out the extreme importance of knowing the characteristics of the coal to be used before attempting to design or to equip a power plant. It is of just as much importance to know the characteristics and the chemical contents of the coal to be used as it is to know the chemical composition and the tensile and compressive strength of a piece of iron or steel before designing a mechanism in which iron or steel is to be used. The study of the coal and of the coal fields brings out strongly not only the great variations of the coals of the several fields, but also the great variations that exist between coals from the same field. These variations range from lignite to anthracite, and it has been seen that the heating power of different coals from some fields varies from 7,000 to 14,000 B. T. U. per pound. This means that to produce the same power, more than 2 tons of the former coal would have to be burned in the same interval of time that 1 ton of the later coal would be burned. The poorer coal, undoubtedly, would be a slower-burning coal than the good grade; consequently, more than twice as much of the poorer coal would have to be burned on the grates at any instant to develop the same heat value. This statement will give an idea of how the use of these two coals would affect the grate area, the boiler construction, and the chimney proportions of the installation, and how different the provisions for handling the coal and the ash would have to be. Also, it will give an idea of what the efficiency of a plant would be if

designed for using the better coal and made to burn the poorer grade. Then, again, many of the low-grade coals ignite more easily than the better grades of coal, but the flame produced requires more draft to be self-sustaining. Also, when fresh coal is put on the fire, a very much larger volume of air is required to prevent dense, black smoke than is necessary with the good grades of coal. In fact, there are such wide variations in coals that the only way to insure success in designing and equipping a plant is to know the percentages of the chemical contents of the coal that is to be used.

CHAPTER IX

ANALYSIS OF COAL

T HE TRUE TEST of any coal lies in its burning. On the other hand, the character, quality, and quantity of the coal content gives a reliable indication of what might be expected from the use of a coal. Furthermore, coal can be purchased under specifications as to the chemical contents, and a knowledge of the chemical contents makes it possible to determine whether or not such coal as was specified has been delivered. The contents of coal are determined by analysis, and the constituents for which the coal is analyzed are the moisture, the volatile matter, the fixed carbon, the ash, and the sulphur. The heat value of a coal can be calculated from the coal contents, or, as is usually the case, it can be determined by burning a portion of the sample in a calorimeter so as to determine the heat value directly.

Two kinds of analysis, therefore, are made—the proximate, and the ultimate. A proximate analysis determines by mechanical processes the amount or percentage of moisture, volatile matter, fixed carbon, and ash in the coal; an ultimate analysis determines by chemical processes the chemical elements contained in the coal; that is, the hydrogen, carbon, nitrogen, oxygen, sulphur, and ash. For general purposes, a proximate analysis is satisfactory, but when very accurate results are desired, an ultimate analysis is necessary. A proximate analysis of coal is expressed as follows:

PROXIMATE ANALYSIS

	PER CENT.
Fixed carbon	52.20
Volatile matter	37.58
Moisture	4.17
Ash	6.05
	100.00

The ultimate analysis of the same coal would be expressed as follows:

ULTIMATE ANALYSIS

	PER CENT.
Carbon	72.46
Hydrogen	5.64
Oxygen	13.12
Nitrogen	1.65
Sulphur	1.08
Ash	6.05
	100.00

A brief explanation of the manner in which a proximate analysis is made is as follows:

Moisture is determined by noting the loss in weight of a definite portion of a sample after it has been drying for 60 minutes in a temperature of about 218° F. The loss represents the amount of free moisture in the coal. In purchasing coal under specifications of chemical content, the sample for moisture determination should be taken at the time the coal is weighed at delivery. If taken subsequent to the weighing, the result will work to the disadvantage of either the buyer or the seller, depending on whether the coal has been dried out by the weather or has been rained upon. In the former case, the

analysis will show too low moisture; in the latter, too high moisture.

Coal should not be purchased under specifications calling for a moisture-free analysis. This method compares the coal after it has been freed from all moisture; consequently, it does not take the amount of moisture into account. Two coals that are equally good on a moisture-free basis may, as weighed after shipment, have a difference of 10 or 12 per cent. of moisture. If, therefore, the purchaser buys the high-moisture coal, he is buying the difference in the per cent. of moisture at coal rates. Under the same weather conditions, some kinds of coal will contain much more moisture than others. Semi-bituminous coal, see Table A, is very low; anthracite is higher; bituminous still higher; and so on. A pound of moisture-free coal with originally 1 per cent. of moisture, represents 1.01 pounds of coal as weighed after shipment; a pound of moisture-free coal having, originally, 5 per cent. of moisture, represents 1.05 pounds as weighed after shipment. As these coals on a moisture-free basis are given a value of 1 pound each, instead of 1.01 and 1.05 pounds, respectively, it will be seen that in a moisture-free analysis the coal with the lower moisture content is decidedly at a disadvantage although it is the better coal.

Volatile matter consists of the combustible gases, some incombustible gases, and some water vapor that is combined with the coal and cannot be driven off by merely drying the coal. The percentage of volatile is determined by heating a given weight of the sample, moisture-free, in a closed platinum crucible for 7 minutes over a standard gas flame. This heating drives off the gaseous matter

and leaves the fixed carbon and the ash. The loss
in weight of the sample gives the per cent. of volatile
matter of the coal. Since the per cent. of the vola-
tile matter of coal from the same mine or allied
group of mines is quite uniform, it is a very good
standard for designating coals.

Fixed carbon is determined by continuing the
burning, after determining the volatile matter, until
nothing but the ash remains. The loss in weight
from the weight of the volatile-free sample, gives
the amount of fixed carbon in the coal.

The ash is obtained by deducting the weight of
the crucible from the final weight after burning off
the fixed carbon.

The sulphur is determined by burning a portion
of the sample intimately mixed with some chemical
that will combine with all the sulphur in such a form
that the sulphur can be separated into a pure sulphur
compound and weighed. From this the percentage
of sulphur present can be determined.

Heat-Value Determinations.—The heat value of
a coal is determined by burning a portion of the sam-
ple in closed steel-bomb calorimeter that contains an
excess of pure oxygen. The calorimeter is placed in,
and entirely surrounded by, water of known tem-
perature, and, from the weight of coal burned, the
weight of the bomb and of the water, and the increase
in temperature of the bomb and the water, the total
number of heat units developed by the burning can
be determined. The thermometers used in determin-
ing temperatures by this method should be gradu-
ated to one-thousandth of a degree, and corrections

should be made for the radiation of heat that takes place during the test.

The heating value of the coal is often calculated from the proximate analysis on the assumption that the fixed carbon and a given weight of the volatile combustible have a certain value for all coals. However, any such formula cannot be relied on as accurate, owing to the great variation in the amount of volatile matter in the different coals of the country. This will be better understood by an inspection of Figs. 2, 3, and 4.

The heating value of a coal can be calculated very closely from the ultimate analysis, since the total amounts of the elements comprising the coal content are thereby determined. In burning, 1 pound of each element produces a definite number of heat units. Thus, 1 pound of hydrogen produces 62,000 B. T. U. in burning; 1 pound of carbon, 14,500 B. T. U.; and so on. Knowing the amount of each element in a pound of coal, the heat value of the coal can be calculated, as will be explained under the subject, Combustion of Coal.

In order that the results of analysis from different laboratories may agree and be comparable, the American Chemical Society has prepared standard methods for making proximate and ultimate analyses of coal. All analyses should conform to these standards, and when an analysis is to be made, it should be specified that the Standard method be used. Unfortunately, many chemists employ methods of their own and do not always obtain accurate results with them. Also, when possible, the analysis should be made by a competent chemist who is experienced and skilled in the analysis of coal. Much time and money are wasted, and misleading results

often obtained, through errors in analysis made by careless or inexperienced chemists.

Errors of Analysis.—The most frequent source of error lies in the collecting of the sample for analysis. To collect a truly representative sample of coal of an entire seam of a mine, or, perhaps, of several hundred or thousand tons that are ready for shipment, is no simple matter. The most general error lies in taking too small a sample. Several hundred pounds should be taken as the original sample, and this sample can be reduced to a few pounds for analysis by repeated breaking, mixing, and dividing in such a way as to retain proportional parts of the various constituents of the original sample. This requires a great deal of hard work, as the coal must be pulverized so that it will pass through a 60- or 80-mesh sieve. If this work is not done conscientiously and thoroughly and without the loss of any of the sample, there will creep in an error that will probably make considerable difference in the results of the analysis.

Another error results from improper selection of the sample. Coal has bony pieces containing, perhaps, 80 to 90 per cent. of ash, pieces that are very low in ash and high in heat value, and pieces of almost any intermediate quality. Also, there are lumps and much fine coal. If these are not obtained in their proper proportions, the analysis is valueless.

The greatest variation in analyses from different laboratories lies in the heat value of the coal. This may be due to the type of calorimeter used, to inaccuracy in the standardization of the thermometers used, to the method of manipulating the apparatus, or, to inaccurateness in calculating the results. However, where the samples are properly chosen and

prepared and the Standard method of analysis is used by skilled, experienced, chemists, the results are remarkably close.

Analyses of 300 Kinds of Coal.—A realization of the importance of definite information concerning the analysis and the heat value of the various kinds of coal throughout the country, and of the cost, the loss of time, and the inconvenience that would attend the obtaining of reliable data on this subject, has led the author to compile and include the analysis of more than 300 kinds of coal from .all parts of the. United States. This information is included in Table A, in the appendix, and is especially valuable on account of all the analyses being made by the same method and by a trained force specially detailed for such work by the U. S. Geological Survey. The analyses, therefore, are directly comparable and are thoroughly reliable.

Column 4 of Table A states the kind of coal the sample was composed of. In this column, the letter P stands for peat; L, for lignite; S, for subbituminous coal; B, for bituminous coal; Sb, for semibituminous; Sa, for semianthracite; A, for anthracite; and G, for graphite. Column 5 gives the per cent. of nitrogen in each sample; column 6, the per cent. of sulphur; 7, the per cent. of hydrogen; 8, the per cent. of carbon; 9, the per cent. of oxygen; 10, the per cent. of ash; 11, the moisture; 12, the fixed carbon; 13, the volatile matter; 14, the ratio of the carbon, to the ash plus the oxygen; 15, the heat value, in calories, determined by the means of a Mahler bomb calorimeter; 16, the heat value in British thermal units (B. T. U.) calculated from the values given in column 15; 17, the geological period of the formation of the coal; 18, the geological rock

formation; and 19, remarks relative to the nature of the sample and the place from which it was taken.

The table is arranged according to the numerical sequence of the ratio, $\dfrac{C}{O + ash}$, on the assumption that oxygen and ash are of practically equal anti-calorific value. That the assumption is true is shown by a comparison of the values in columns 14 and 15. The values in column 15 were obtained by burning the samples of coal in a calorimeter.

This table shows clearly the value of analysis in determining the true heat value of a coal. To bring out the point more clearly, Table XIV is prepared from the three analyses, Nos. 144, 140, and 123, of Table A. The columns in Table XIV are numbered to correspond with like columns in Table A.

TABLE XIV.

Heat Value of Coals of Different Ages.

1	3	4	8	9	10	9 and 10	14	15	17
No.	Designation of Coal.	Kind.	C.	O.	Ash.	Sum of 9 & 10	C./O+Ash.	Heat Units, B.T.U.	Age.
144	Wyo. 5	S.	70.30	18.32	3.63	21.95	3.20	12,429	Cretaceous
140	Va. 5a	Sa.	72.23	18.80	4.02	22.82	3.16	12,382	Carboniferous
123	Ark. 1B	Sb.	70.25	4.03	19.26	23.29	3.01	12,186	Carboniferous

Table XIV shows a subbituminous coal of the Cretaceous period that has a higher heat value than either a subbituminous or a semianthracite coal of

the Carboniferous period. The age of the coal, therefore, does not determine the true heat value of a fuel, the heat value being dependent on the relative proportion of the total carbon to the sum of the oxygen and ash. Columns 2 and 4, Table A, Appendix, show how arranging the coals according to their heat value mingles fuels of different kinds, characters, and ages, the high oxygen of the younger coals often being offset by the high ash of the older coals.

CHAPTER X

THE PURCHASING OF COAL

ADAPTING the Coal to the Plant.—In purchasing coal for heat or power purposes, two things must be considered— the adaptability of the coal to the plant that is to burn it and the heat value, or B. T. U., of the coal.

Table A shows that fuels differing widely in nature and characteristics may have the same heat value and yet not be equally valuable to the purchaser. The coal purchased must conform to the type and the setting of the boiler plant. Anthracite and the other low-volatile coals require a large grate area because they are slow-burning; whereas, coals high in volatile are fast-burning and require a much smaller grate area. Also, the furnace for burning high-volatile coals must be designed differently from the furnace for low-volatile coals, so as to prevent smoke and loss of boiler efficiency. A high-volatile coal burned in a low-volatile coal furnace would steam fairly well, but would smoke badly, and the coal consumption would be very large. A low-volatile coal used in a high-volatile coal furnace would not smoke, but sufficient coal could not be burned to develop the full capacity of the plant. The furnace construction best suited to the different coals will be treated in proper sequence.

Effect of Impurities on Heat Value.—The size of the monthly coal bill depends on the amount of

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actual coal in each ton and on the heat value of the coal. The amount of coal per ton depends on the impurities in the coal. If a coal contains 20 per cent. of impurities, each ton contains only 1,600 pounds of coal; whereas, with 8 per cent. of impurities, each ton would contain 1,840 pounds. In the purchase of 100 tons, the first coal would contain only 80 tons of actual coal, while the second coal would contain 92 tons, or a difference of 12 tons. This, however, is not the entire difference in the two coals that must be charged to the impurities. Every 4 per cent. of moisture in the fuel requires 1 per cent. of fuel to evaporate it. Every 4 per cent. of moisture therefore displaces 4 per cent. of actual coal in the weighing and uses 1 per cent. of coal for evaporation, a direct loss of 5 per cent. of coal. Sulphur in the form and quantity to cause clinkers carries with it and causes to be shaken into the ashpit an equal percentage of coal. Each per cent. of sulphur, therefore, represents a 2-per-cent. waste of coal, even though half the sulphur is considered volatile. As to the ash, it not only displaces its equivalent of coal, but also is an item of expense in handling and in cleaning the fires. The higher the ash content of a coal, the more the grate must be shaken and the higher the loss through coal being shaken into the ashpit.

Also, another expense chargeable to impurities in the coal is the decreased output, or capacity, of the plant.

Table A shows that the moisture varies from .34 per cent. (No. 237 Pa. 15) to 26.64 per cent. (No. 3 N. Dak. 3); the ash, from 2.38 per cent. (No. 239 W. Va. 14) to 29.33 per cent. (No. 21 Mexico); the oxygen, from 1.82 per cent. (No. 237 Pa. 15) to 38.57 per cent. (No. 2b Wyo. 3694a); the volatile and fixed

carbon, from 14.29 and 76.66 per cent., respectively (No. 242 Ind. T. 9), to 46.94 and 18.72 per cent., respectively (No. 1 Mass. 1); the heat value, from 7,300 B. T. U. to 14,765 B. T. U. per pound of coal.

With such wide variations in the character and in the heat value of the coals of the country, it is evident that the coal should be purchased under a guaranteed analysis, the analysis to be made from undried coal at the point of delivery. This precaution will insure coal of the general character desired. However, since, manifestly, it is impossible to have each shipment conform exactly to a given analysis, the cost of the impurities should be calculated, and where the impurities are higher than the analysis the expense due to the increased impurities should be deducted from the quoted price. When the impurities are less than the contract calls for, then the difference should be added to the quoted price.

Cost of Coal Impurities.—In figuring the cost of impurities in coal, not only the cost of the equivalent amount of coal represented in the amount purchased must be considered, but also any other expense directly chargeable to the presence of the impurity in the coal. It is not customary, however, to take account of the reduction of boiler efficiency or capacity due to the impurities, for the reason that the specifications fix the character and the approximate amounts of the impurities; hence, the variations should not be sufficient to affect the efficiency or capacity of the plant appreciably.

The cost of moisture is calculated on the basis that 1 per cent. of moisture will displace 1 per cent. of coal and that it will require 1 per cent. of coal to evaporate 4 per cent. of moisture. Assume that the

of coal wasted in the ashpit will appear as 1 per cent. of ash.   Half the sulphur is volatile, leaving ½ per cent. ash.   The cost of handling this 1½ per cent. of

TABLE XV.

Cost, in Cents, for 1 Per Cent. Moisture, Sulphur, and Ash, in Coal.

Coal as Delivered.	Quoted Price, in Dollars Per Ton, Delivered.						
	$1.00	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00
	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents
Moisture { First cost	$1.00	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00
Cost to evaporate	.25	.38	.50	.63	.75	.88	1.00
Cost to fire	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Total cost	2.50	3.13	3.75	4.38	5.00	5.63	6.25
Sulphur { First cost	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Cost of coal wasted	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Cost to fire	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Removing ash	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total cost	5.50	6.50	7.50	8.50	9.50	10.50	11.50
Ash { First cost	1.00	1.50	2.00	2.50	3.00	3.50	4.00
Cost to fire	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Removing ash	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total cost	3.00	3.50	4.00	4.50	5.00	5.50	6.00

ash is 1½ cents.   The total cost, therefore, 2 + 2 + 1½ = 5½ cents for each per cent. of sulphur in the coal.   For cost of a greater per cent. of

sulphur, or for higher-priced coal, proceed as in the case of moisture.

The cost of ash is calculated as follows: 1 per cent. of ash displaces 1 per cent. of coal and costs 1 cent. Cost of firing the 1 per cent. of coal, 1 cent; cost of removing the 1 per cent. of ash, 1 cent. The total cost, therefore, is 3 cents.

Table XV gives the cost of impurities for coals of different prices.

Equating Coals of Different Impurities.—As a general rule, coal purchased under contract is specified according to a certain proximate analysis. Assume that the contract calls for a coal having 2 per cent. of moisture, 1.0 per cent. of sulphur, and 6 per cent. of ash, with a guaranteed heat value of 14,000 B. T. U., the price per ton, delivered, to be $3.50 net. Assume, also, that the coal delivered analyzes 4 per cent. of moisture, 1.5 per cent. of sulphur, and 8 per cent. of ash, and has a heat value of only 13,500 B. T. U. What should be the equated price of the coal, as furnished?

According to the price quoted in the contract, the impurities in the coal contracted for would cost:

	CENTS
Moisture, 2 per cent., 2×5.63......	11.26
Sulphur, 1 per cent., 1×10.50......	10.50
Ash, 6 per cent., 6×5.50..........	33.00
Total	54.76

The equated price of the coal contracted for, therefore, would be $3.50 plus 54.76, or $4.05 per ton.

The total heat value for a ton would be 2,000 $\times$

$14,000 = 28,000,000$ B. T. U., and the cost per million B. T. U. would be $\dfrac{4.05}{28} = 14.46$ cents.

The cost of the impurities in the coal delivered would be as follows:

	CENTS
Moisture, 4 per cent., 4×5.63......	22.52
Sulphur, 1.5 per cent., 1.5×10.5....	15.75
Ash, 8 per cent., 8×5.50..........	44.00
Total	82.27

The equated price for the coal delivered, therefore, would be 3.50 plus 82.27, or 4.32 cents per ton. The total heat value for a ton would equal 2,000 times 13,500, or 27,000,000, B. T. U., and the cost per million B. T. U., would equal $\dfrac{4.32}{27} = 16$ cents. This is, $16 - 14.46 = 1.54$ cents per million B. T. U. in excess of the price agreed on in the contract, or $27 \times 1.54 = 41.5$ cents per ton, so that 41.5 cents is subtracted from the contract price of the coal, making the coal cost $3.50 - .415 = \$3.085$ per ton, instead of $3.50.

If the coal delivered is better than the contract calls for, the problem would be worked out in a similar manner, but the difference in the price per ton would have to be added to the original contract price.

CHAPTER XI

THEORY OF COMBUSTION

General Definitions

COMPOSITION **of Matter.**—Every body or mass of matter is an elementary substance, a compound substance, or a mechanical mixture. An elementary substance is composed of only one element; therefore, is not formed through chemical combination. Silver and gold and the gases known as oxygen, hydrogen, and nitrogen are some of the elementary substances. A compound substance is formed by the chemical combination of two or more elements. The compound, water, is formed by the chemical combination of hydrogen and oxygen. Since a compound substance is the result of a chemical combination, it can be decomposed into its elements. By passing a current of electricity through water it will decompose the water into its elements, hydrogen and oxygen. Any substance, therefore, that can be decomposed into other substances must be a compound. Examples of compounds are coal, fuel and light gas, and water.

An elementary substance is composed of only one element; consequently, it is impossible to decompose an element. Its form can be changed only by combining it chemically with one or more other elements. The elements that are of direct interest in the study of the combustion of coal are the gaseous elements oxygen, hydrogen, and nitrogen, and the solid elements carbon, sulphur, and iron.

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A mechanical mixture may be composed of two or more elements, of two or more compounds, or of elements and compounds mechanically mixed, but not chemically combined. The air of the atmosphere is a mechanical mixture composed principally of the elements oxygen and nitrogen.

Atoms and Molecules.—All matter, be it an element, a compound, or a mixture, is made up of a comparatively small number of elementary substances, only about seventy-two elements being known up to the present time.

As a matter of convenience, the elements are designated by symbols, which are usually the first letter or letters of their names. Thus, H stands for hydrogen; O, for oxygen; N, for nitrogen; C, for carbon; S, for sulphur; and Fe (from the latin *ferrum*), for iron. A compound is designated by combining the symbols of its elements. Thus, water is expressed by the symbol H_2O, the suffix 2 indicating that 2 atoms of hydrogen have combined with 1 atom of oxygen.

The smallest quanity of an element or a compound that is capable of separate existence is taken as a physical unit of matter, and is called a molecule. Molecules are composed of atoms of elements. An atom is the smallest part of an element that can enter into a compound or be expelled from it. Atoms never exist singly, but always combine with one or more other atoms to form a molecule. The molecules of most elementary gases, like oxygen, hydrogen, and nitrogen, are supposed to consist of 2 atoms. Also, equal volumes of these gases, under the same conditions of temperature and pressure, are supposed to contain the same number of mole-

of hydrogen will be unassociated. If 1 volume of H is mixed with 1 volume of O, one-half of the oxygen will remain unassociated. Oxygen, unfortunately for efficiency of combustion, combines with carbon in either of two proportions: as carbon monoxide, C O, or as carbon dioxide, CO_2. As C O, the carbon is only partly burned and is capable of combining with another atom of oxygen to form CO_2.

If, as assumed, the atoms of hydrogen, oxygen, nitrogen, and carbon are of equal size, then the relative weights of equal volume of these substances under the same pressure and temperature will be the same as the relative weights of their molecules and, therefore, as their atomic weights. As hydrogen is the lightest substance known, its weight is taken as unity in the table of atomic weights, Table XVI.

TABLE XVI.

Atomic Weights of Elementary Substances Concerned in Combustion.

Element.	Symbol.	Atomic Weights.		Density, Air = 1.	Weight, Pounds Per Cubic Foot, at 32° F. Under 1 Atmosphere.
		Approximate.	Accurate.		
Hydrogen	H	1	1.008	.9692	.00559
Carbon ..	C	12	12.000		
Nitrogen .	N	14	14.010	.9701	.07831
Oxygen ..	O	16	16.000	1.10521	.08884
Sulphur ..	S	32	32.070		

By the aid of Table XVI, the weight of any compound substance formed during combustion can be obtained from the chemical formula of the substance. Thus, in water, H_2O, the 2 atoms of H weigh 2 and the 1 atom of O weighs 16; therefore, the molecular

weight of water is $16 + 2 = 18$. Water is thus composed, by weight, of 2 parts of H and 16 parts of O, and the ratio of H to O, by weight, is 1 to 8. By volume, water is composed of 2 volumes of H and 1 volume of O. These 3 volumes unite and form only 2 volumes of water in its gaseous state, the 2 volumes representing the space of the original 2 volumes of H. The relative weights of H_2O and H, therefore, are as 18 is to 2 or as 9 is to 1; that is, under the same temperature and pressure, water vapor weighs 9 times as much as the same volume of hydrogen.

ELEMENTS OF COMBUSTION

Hydrogen.—Hydrogen is a colorless, tasteless, inodorous gas. It was discovered in 1766 by Cavendish, who called it inflammable air. Its weight or density, compared with that of air, is as .0692 is to 1. It is very widely distributed, forming 11 per cent. of water, about 5.25 per cent. of wood, and from 3.5 to 6 per cent. of coal. Hydrogen does not unite readily with oxygen at ordinary temperatures, but when heated to its igniting temperature it burns readily with a colorless or slightly blue flame, forming water vapor. When mixed with oxygen, it is explosive. Its density is .0692 (air $= 1$), and its weight at $32°$ F. under atmospheric pressure is .00559 pound per cubic foot.

Carbon.—Carbon uncombined is a solid. It is very widely distributed, being the central element in all organic matter, whether vegetable or animal. It occurs principally in combination with various elements, but is found uncombined as coke, charcoal, lampblack, graphite, diamond, and, in an impure state, as coal. At high temperatures, carbon has a very strong affinity for oxygen with which it combines readily. The atomic weight of carbon is 12.

Nitrogen.—The element nitrogen is a gas that has no color, taste, or odor. It will not combine with oxygen; consequently, it will not burn. However, it combines readily with other elements, forming saltpeter, sodium salt, ammonia, etc. It forms four-fifths of the atmosphere, where it acts as a diluent and renders burning less active that it would be in oxygen alone. Nitrogen plays no part in the combustion of a fuel, and it passes through the furnace without change. It dilutes the oxygen and renders the action of the burning less active than it would be if the oxygen were pure; also, in passing through the furnace it absorbs heat, which is carried with it through the stack and lost. Furthermore, it decreases the temperature of the products of combustion by increasing the volume of gases that must be heated by the combustion of the coal. The density of nitrogen, where air is equal to 1, is .9701; its weight per cubic foot at 32° F. and under atmospheric pressure is .07831 pound; its atomic weight is 14.

Oxygen.—At ordinary temperatures, oxygen is tasteless, odorless, inodorous gas. It is the most abundant of all the elements, being found in a free state in the air, where it forms one-fifth the volume of the atmosphere. It is combined in water and is found in most substances that form the crust of the earth. It is the only element that will support combustion and respiration, and is absolutely necessary in animal and vegetable life.

Sulphur.—As has been seen, sulphur may be present in coal in either a free state or in a combined form. In the form of sulphates, it has no heating value. Sulphur is objectionable because the gases formed by its combustion attack the metal of the

boiler, particularly in the presence of moisture, caus-
ing rapid corrosion of the metal. The atomic weight
of sulphur is 32.

CARBON AND HYDROGEN

Oxygen combines with hydrogen in one propor-
tion only, since the combination invariably produces
water, according to the reaction $2H + O = H_2O$.

Oxygen combines with carbon in two propor-
tions. If carbon at a sufficiently high temperature
is supplied with sufficient oxygen, each atom of car-
bon will unite with 2 atoms of oxygen, according to
the reaction $C + 2O = CO_2$. The CO_2 is a colorless
gas that is slightly acid to taste and smell and is
called carbon dioxide, or carbonic acid. It is about
one and a half times as heavy as air, is incombus-
tible, and will support neither life nor combustion.
It is not poisonous, but since it is much heavier than
the air, weighing 1.529 times as much, it will exclude
the oxygen and thus produce death through suffo-
cation. The usual amount of oxygen in the air is
about 20 per cent. If sufficient CO_2 is present to
reduce the O to 17 per cent., the flame of a lamp will
be extinguished. An atmosphere with sufficient CO_2
to reduce the oxygen below 10 per cent. is dangerous
to life. Since 2 atoms of oxygen are the most that 1
atom of carbon can combine with, the combustion is
said to be complete when the carbon is burned to
CO_2. Since 1 atom of carbon weighs 12 and 2 atoms
of oxygen weigh $2 \times 16 = 32$, the molecular weight
of CO_2 is $12 + 32 = 44$; that is, it consists of 12
parts, by weight, of carbon and 32 parts of oxygen.

In an insufficient supply of oxygen, carbon
unites with oxygen according to the reaction $C + O$
$= CO$. Also, under these conditions, if CO_2 comes

into contact with the incandescent carbon, the following reaction will take place: $CO_2 + C = 2CO$. The CO is a colorless, practically inodorous, poisonous gas, called carbonic oxide or carbonmonoxide, that is destructive to animal life. The presence of but a small volume in the air quickly produces insensibility and death. It combines with the red corpuscles of the blood more readily than oxygen does, and the blood becomes saturated with CO and cannot take up oxygen and distribute it throughout the system. In combining with the red corpuscles, it forms a bright-red compound, called carboxyhemoglobins. Air containing 1.5 per cent. of CO will overpower a man almost in an instant. Haldane states that an atmosphere containing over .2 per cent. of CO would be very dangerous to man, and .02 per cent. might cause headache and disablement; .2 per cent. would probably cause a man at rest to collapse in 1 hour. CO will not support combustion, but it will burn according to the reaction $CO + O = CO_2$. An explosive mixture is made with 15.5 per cent. of CO in the air. CO is slightly lighter than air, having a specific gravity of .967, where air is equal to 1. The atomic weights of the elements being 12 and 16, the molecular weight is $12 + 16 = 28$.

HYDROCARBONS

Carbon and hydrogen are found in the combined state in liquid, solid, and gaseous forms, as the bitumen of bituminous coal. Bitumen is a natural mixture of hydrocarbons; that is, it is a compound formed by the chemical combination of hydrogen with carbon. The hydrocarbons are distilled from coal in the form of gases, oils, and tars. The gases

are distinguished for purposes of combustion as light hydrocarbons and as heavy hydrocarbons.

Methane.—Methane, CH_4, is commonly known under the name of marsh gas. It derives the name marsh gas from the fact that it escapes as bubbles from decaying vegetation below the surface of water in marshes, etc., and may be collected and burned. Also, it is known as the light hydrocarbon gas of coal, because its molecular weight is only 16, while the molecular weight of the heavier hydrocarbon gas ethylene, C_2H_4 (olefiant gas), is 26, and benzole, C_6H_6, or benzine, as it is better known, is 78, Table XVII.

Methane is a colorless, tasteless, odorless gas. It is not poisonous, but if present in sufficient quantities it will cause death by suffocation. Methane is a very valuable part of the fuel, as it forms the bulk of the hydrocarbon gases and burns at a temperature of 1,202° F. As it consists of 4 parts of H to 1 part of C, it furnishes a good supply of readily available heat with but little tendency to smoke. It possesses practically no illuminating properties on account of its low carbon content; consequently, it burns with a flame that is not very luminous. It forms explosive mixtures between the limits of 5.5 and 13 per cent. of methane in air. The explosion is not violent at the lower limit, and the spread of the flame can readily be followed with the eye. As the mixture is increased up to about 9.5 per cent., the explosion increases in violence, after which it decreases in violence until the upper limit is reached. Above 13 per cent. and below 5.5 per cent., burning occurs under proper conditions, according to the reaction:
$$CH_4 + 4O = CO_2 + 2H_2O.$$

Acetylene. — Acetylene, C_2H_2, is a colorless,

tasteless, gas of peculiar odor. It burns in air with a brilliant, but smoky flame. It ignites at 900° F., which is lower than the igniting temperature of any other coal gas or any natural gas. The glowing end of a cigar will ignite acetylene. It is slightly poisonous, and its explosive limits are between 3 and 65 per cent. It burns according to the reaction $C_2H_2 + 5O = 2CO_2 + H2_2O$.

Ethylene and Ethane. — Ethylene, C_2H_4, often called olefiant gas, and ethane, C_2H_6, and benzole, or benzene, C_6H_6, are the heavy hydrocarbon gases of the coal. They are very rich in carbon; consequently they burn in air with a very luminous but smoky flame. Unless the air conditions and the temperature are just right, it is difficult

TABLE XVII.

Heat Value of 1 Pound of Hydrocarbon at 32° F. and Atmospheric Pressure.

Name of Gas	Molecular Weight	Chemical Symbol	Pounds of		Cubic Feet of Gas per Pound	B. T. U. per		Cubic Feet of Air Required per Pound		
			C.	H.		Pound.	Cubic Foot.	Carbon	Hydrogen	Total.
Carbon monoxide	28	CO	12/28	0	12.77	4,400	344	32	000	32
Hydrogen	1	H	0	1	177.90	62,100	349	000	454	454
Methane	16	CH_4	12/16	4/16	22.42	23,515	1,049	114	114	228
Acetylene	26	C_2H_2	24/26	2/26	13.79	21,460	1,566	140	35	175
Ethylene	28	C_2H_4	24/28	4/28	12.80	21,370	1,675	132	65	197
Ethane	30	C_2H_6	24/30	6/30	11.94	22,230	1,862	120	92	212
Benzole	78	C_6H_6	72/78	6/78		18,184		140	35	175

AIR REQUIRED FOR COMBUSTION

Source of Oxygen Supply.—By combustion, or burning, is meant the very rapid chemical combination of oxygen with any combustible or fuel material, producing both heat and light. The substance with which the oxygen combines is called the combustible of the coal; the oxygen supports the combustion. The chief combustibles in coal are the carbon and the hydrogen. Combustion is said to be perfect when the combustible combines with all the oxygen that it is capable of combining with; if it combines with less than that amount, the combustion is said to be imperfect. Thus, the burning of carbon to carbon dioxide, CO_2, gives perfect combustion, since CO_2 cannot unite with more oxygen. Burning carbon to carbon monoxide, CO, gives imperfect combustion, since the CO can be burned to CO_2 by uniting with another atom of oxygen.

The supply of oxygen necessary for combustion is obtained from the atmosphere, which is a mechanical mixture, by volume, of 78.35 parts of nitrogen, 20.77 parts of oxygen, .84 parts of aqueous vapor, and .04 part of carbonic acid. Neglecting the last two constituents, the atmosphere, by weight, consists of 76.85 parts of nitrogen and 23.15 parts of oxygen; that is, the oxygen is diluted in about three times its weight of nitrogen. If air equals 1, then the density of oxygen is 1.10521; its weight is .088843 pound per cubic foot at 32° F. and under atmospheric pressure. One pound of oxygen is contained in 4.32 pounds of air.

Burning Carbon to Carbon Dioxide.—In completely burning carbon, it forms CO_2; that is, 12

4.43 pounds of CO_2 and H_2O, a total of 15.82 pounds. The $2CO_2$ is $\dfrac{88}{124}$ of the 4.43 pounds, or 3.14 pounds, and the $2H_2O$ is $\dfrac{36}{124}$ of the 4.43, or 1.29, pounds.

Burning Acetylene. — In burning acetylene, C_2H_2, to $2CO_2 + H_2O$, $5 \times 16 = 80$ pounds of oxygen combine with 26 pounds of C_2H_2; therefore, $\dfrac{80}{26} =$ 3.07 pounds of oxygen must be supplied for each pound of C_2H_2. This requires $4.32 \times 3.07 = 13.26$ pounds of air, and the products of combustion will be $13.26 - 3.07 = 10.19$ pounds of nitrogen and $3.07 + 1 = 4.07$ pounds of CO_2 and H_2O, a total of 14.26 pounds. The CO_2 is $\dfrac{44}{80}$ of 4.07, or 2.24 pounds, and the H_2O is $\dfrac{36}{80}$ of 4.07, or 1.83, pounds.

Burning Ethane.—In burning ethane, C_2H_6, to $2CO_2 + 3H_2O$, $7 \times 16 = 112$ pounds of oxygen combine with 30 pounds of C_2H_6; therefore $\dfrac{112}{30} = 3.73$ of oxygen must be supplied for each pound of C_2H_6. This requires $4.32 \times 3.73 = 16.11$ pounds of air, and the products of combustion will be $16.11 - 3.73 = 12.39$ pounds of nitrogen and $3.72 + 1 = 4.72$ pounds of CO_2 and H_2O, a total of 17.11 pounds. The CO_2 is $\dfrac{44}{80}$ of 4.72, or 2.6 pounds and the H_2O is $\dfrac{36}{80}$ of 4.72, or 2.22, pounds.

Benzole.—In burning benzole, C_6H_6, to $6CO_2 + 3H_2O$, $15 \times 16 = 240$ pounds of oxygen combine with 78 pounds of C_6H_6; therefore, $\dfrac{240}{78} = 3.07$ pounds of

oxygen must be supplied for each pound of C_6H_6. This requires 13.26 pounds of air, and the products of combustion will be 10.10 pounds of N, 2.24 pounds of CO_2, and 1.83 pounds of H_2O, a total of 14.17 pounds.

Sulphur.—In burning sulphur to sulphuric dioxide, SO_2, 32 pounds of sulphur combine with 32 pounds of oxygen, so that 1 pound of oxygen must be supplied for each pound of sulphur. This requires 4.32 pounds of air, and the products of combustion will be $4.32 - 1 = 3.32$ pounds of nitrogen and $1 + 1 = 2$ pounds of SO_2, a total of $3.32 + 2 = 5.32$ pounds.

The theoretical quantities of air necessary to furnish the required amount of oxygen, together with the products of combustion for each combustible, are given in Table XVIII.

Density, Weight, and Volume of Gases.—The density, weight, and volume of the gases that are related to the process of combustion are given in Table XIX. The volume of the gases for any temperature and pressure other than those given in this table may be found from the formula:

$$V_0 = V_1 \frac{P_1 T_0}{P_0 T_1}$$

in which, V_1 equals the volume given in Table XIX; V_0, the volume corresponding to the absolute pressure P_0 and the absolute temperature T_0; P_1, the absolute pressure given in Table XIX (atmospheric pressure), 14.7; P_0, the absolute pressure corresponding to the volume V_0 and the absolute temperature T_0; T_0, the absolute temperature after change of volume $(460 + t_0)$; and T_1, the absolute temperature before change of volume $(460 + t_1)$, t_1,

TABLE XVIII.

Air Necessary for Combustion of Carbon, Hydrocarbons, and Sulphur at 60° F.

Combustible, 1 Pound of:	Chemical Symbol	Atomic Weight	Chemical Reaction	Weight of Oxygen Required per Pound of Combustible.	Air Necessary to Supply Required Oxygen per Pound of Combustible at 60° F. Lbs.	Cubic Feet, = Pounds × 13.14	Pounds of Nitrogen in the Air.	Total Pounds.	Products of Combustion. Composition and Weight. Pounds.
Carbon, to CO_2	C	12	$C + 2O = CO$	2.67	11.53	152	8.86	12.53	3,67 CO_2 and 8,86 N
Carbon, to CO.	C	12	$C + O = CO$	1.33	5.75	76	4.42	6.75	2.33 CO_2 and 4.42 N
CO to CO_2	CO	28	$CO + O = CO_2$	0.57	2.46	32	1.89	3.46	1.57 CO_2 and 1.89 N
Hydrogen	H	1	$2H + O = H_2O$	8.00	34.56	454	26.56	35.56	26.56 N and $9H_2O$ vapor
Methane	CH_4	16	$CH_4 + 4O = CO_2 + 2H_2O$	4.00	17.28	227	13.28	18.28	2.75 CO_2, 13.28 N, and 2.25 H_2O
Ethylene	C_2H_4	28	$C_2H_4 + 6O = 2CO_2\ 2H_2O$	3.43	14.82	195	11.39	15.82	314 CO_2, 11.39 N, & 1.29 H_2O
Acetylene	C_2H_2	26	$C_2H_2 + 5O = 2CO_2 + H_2O$	3.07	13.26	175	10.19	14.26	2.24 CO_2, 10.19 N, and 1.83 H_2O
Ethane	C_2H_6	30	$C_2H_6 + 7O = 2CO_2 + 3H_2O$	3.72	16.11	212	12.39	17.11	26 CO_2, 12.39 N, and 2.02 H_2O
Benzole	C_6H_6	78	$C_6H_6 + 15O = 12CO_2 + 3H_2O$	3.07	13.26	175	10.19	14.26	2.24 CO_2, 10.19 N, and 1.83 H_2O
Sulphur	S	32	$S + 2O = SO_2$	1.00	4.32	57	3.32	5.32	3.32 N and 2 SO_2

and t_0 bring the temperatures of the gas in degrees Fahrenheit, before and after the change of volume, respectively.

EXAMPLE.—Find the volume of 5 pounds of dry air at atmospheric pressure and at 80° F.

SOLUTION.—Since $V_1 = 12.390$ cubic feet (from Table XIX), $P_1 = 14.7$ pounds per square inch; $P_0 = 14.7$ pounds per square inch; $T_1 = 460 + t = 460 + 32 = 492°$ F.; and $T_0 = 460 + t_0 = 460 + 80 = 540°$ F. Then, for 1 pound of air,

$$V_0 = V_1 \frac{P_1 T_0}{P_0 T_1} = 12.390 \times \frac{14.7 \times 540}{14.7 \times 492} = 12.390 \times \frac{540}{492} = 13.6 \text{ cubic feet}$$

The volume of 5 pounds of air at 80° F. would be, $5 \times 13.6 = 68.0$ cubic feet.

TABLE XIX.

Density, Weight, and Volume of Gases at 32° F. and Atmospheric Pressure.

Gases	Chemical Symbol	Relative Density, H=1	Weight, pound per cubic foot at 32° F.	Volume cubic feet per pound at 32° F.
Air.............		14.44	.08071	12.390
Oxygen.........	O	15.96	.08922	11.208
Hydrogen.......	H	1.00	.00562	177.900
Nitrogen........	N	14.00	.07831	12.770
Carbon monoxide.	CO	13.97	.07807	12.810
Carbon dioxide...	CO_2	21.95	.12267	8.152
Methane........	CH_4	7.99	.04470	22.371
Ethylene........	C_2H_4	13.97	.07809	12,805
Acetylene.......	C_2H_2	13.29	.07254	13.785
Ethane..........	C_2H_6	15.52	.08379	11.935
Sulphur dioxide..	SO_2	31.96	.17865	5.598
Water vapor.....	H_2O	8.98	.05020	19.922

EXAMPLE.—Find the volume of 5 pounds of dry air at 85° F., and under an absolute pressure of 29.4 pounds per square inch.

SOLUTION.—$V_1 = 12.390$ cubic feet; $p_1 = 14.7$ pounds per square inch; $P_0 = 2 \times 14.7 = 29.4$ pounds per square inch; $T_1 = 492°$ F.; and $T_0 = 460 + 85 = 545°$ F. Therefore, for

$$1 \text{ pound of air, } V_0 = 12.390 \times \frac{14.7 \times 545}{29.4 \times 492} = 554 \text{ cubic feet,}$$

and for 5 pounds, $V_0 = 5 \times .554 = 2.77$ cubic feet.

COMBUSTION OF COAL

FUEL **Elements of Coal.**—Carbon, the chief fuel element of coal, is found both uncombined as fixed carbon and combined as free carbon in a series of some fifty compounds of hydrogen and carbon, called hydrocarbons. The simplest of this series of hydrocarbons are the methane, CH_4, and the ethylene, C_2H_4. The elements, hydrogen and carbon, forming this series exist in the combined state in the fuel or, upon the absorption of heat by the fuel, become associated in the chemical combinations that go to form the hydrocarbons. Owing to the conditions under which combustion takes place, it is impossible to give the exact order of the process. However, it is positively known that the final products of complete combustion should be CO_2, H_2O, N. and possibly some sulphurous acid, SO_2.

Volatilizing the Hydrocarbons. — When bituminous coal is thrown on a fire, the process of combustion takes place after the following order: The coal first absorbs heat, which raises its temperature; also, the heat performs internal work in volatilizing and driving off the hydrocarbons and gases of the coal. First, the moisture and the CO_2 are driven off. Then the CO and, between 700° and 800° F., the napthalene, tars, and resins, and volatile fluids with high boiling points commence to disengage. Next come the illuminants C_2H_4, etc. and the light carbureted hydrogen, CH_4. The hydrogen begins to be

volatilized at about 900° F.   By the time the coal has become brightly incandescent, between 1,800° and 2,000° F., the hydrocarbons and the hydrogen are practically all volatilized. As the volatile matter is driven off, provided the temperature in the furnace is high enough and there is a sufficient supply of oxygen present to mix intimately with the gases and burn them, they will ignite and burn with a long flame.

When the fixed carbon of the coal has attained a temperature of about 800° F., it will begin to unite with the oxygen of the air and burn with a bright glow, but no flame, forming CO_2.

As the temperature of the fixed carbon increases, its rate of combustion increases. Also, CO_2 rising through the bed of the fire comes in contact with the highly heated carbon and splits up, according to the reaction $CO_2 + C = 2CO$. If the CO now comes in contact with oxygen at the proper temperature, the CO will take an another atom of oxygen and again form CO_2. If the supply of oxygen is insufficient, or if the temperature is too low, the CO will pass off unconsumed and thus waste fuel.

Before oxygen will combine with the hydrocarbons, they must be dissociated, or separated, into their elements H and C by the heat of the furnace. The temperature at which dissociation occurs depends on the nature of the compound. For example, methane, CH_4, requires a temperature of 1,202° F., while ethylene, C_2H_4, requires a temperature of only 1,022° F. After dissociation, combustion occurs according to the following order: First, the hydrogen combines with the oxygen and forms water; then, provided a sufficient supply of oxygen is present, the carbon combines and burns completely to CO_2; if the

supply of oxygen is limited, the incandescent particles of carbon that are liberated from the gas may become cooled below their igniting temperatures before they come in contact with a supply of oxygen, so that the chemical combination may not take place even in an abundance of oxygen. Therefore, whether all the carbon will pass up the stack as CO_2, or whether a portion will escape as CO or as C, depends on the temperature in the furnace, the arrangement of the furnace to provide sufficient combustion space, the proportion of oxygen at hand, and the arrangement involved in the breaking up of the oily and carbons.

Before the oils and tars of the fuel will burn, they must be vaporized, gassified, and, lastly, dissociated. It will thus be seen that there is a time element involved in the breaking up of the oily and tarry hydrocarbons that must be given special attention if the fuel is to be burned without objectionable black smoke.

Igniting Temperature.—Every combustible substance has a definite temperature, called its igniting temperature, at which it will unite with oxygen and burn, and below which it will not burn. The igniting temperature varies greatly for different substances; some substances require only a slight increase in temperature before they burn, while others must be heated to a very high temperature. For example, phosphorus will burn at 150° F.; sulphur, at 470° F.; and hydrogen, at 1,130° F. Table XX gives the igniting temperatures of various fuels and of the various combustibles that go to make up the fuels.

The French Coal Commission found the temperature of ignition of CH_4 to be 1,436° F. when

TABLE XX.

Igniting Temperatures of Fuels and Combustibles.

Fuels and Combustibles	Temperature of Ignition, Degrees F.
Anthracite, fixed carbon....................	925
Semibituminous coal, fixed carbon..........	870
Bituminous coal, fixed carbon..............	766
Cannel coal	688
Coke	Red heat
Dried peat................................	435
Lignite dust..............................	300
Methane, CH_4	1,202
Ethylene, C_2H_4	1,022
Acetylene, C_2H_2	900
Ethane, C_2H_6	1,000
Hydrogen, H...............................	1,130
Carbonmonoxide, CO	1,210
Sulphur, S	470
Phosphorus, P	150

diluted with the proportions of CO_2 and N ordinarily found in furnaces. Also, under furnace conditions, the igniting temperature of CO is 1,290° F.

It will be noted that the temperatures of ignition of the gases of a coal vary from each other and are considerably higher than the temperature of ignition of the fixed carbon of the coals. The temperature of ignition of the coals, of course, is the temperature of ignition for the fixed carbon of the coal, because the gases are roasted out of the coal before the coke burns.

Calculation of Air Required for Combustion of Coal.—The method of calculating the quantity of air required for the combustion of a coal is as fol-

lows: Given, 100 pounds of coal of the composition: Carbon, 80 per cent.; hydrogen, 4.5 per cent.; oxygen, 7.1 per cent.; nitrogen, 1.8 per cent.; sulphur, 1.5 per cent.; and ash, 5.1 per cent. Find the quantity of air needed to burn the coal completely.

The combustible of the coal consists of the carbon and the hydrogen. In the 100 pounds of coal under consideration there is 80 per cent. of 100 pounds, or 80 pounds, of carbon and 4.5 pounds of hydrogen. The 1.5 pounds of sulphur is considered as one-half combustible, so that the air required to burn .75 pound of sulphur must be supplied. The 1.8 pounds of nitrogen is inert, and, like the 5.1 pounds of ash, is incombustible and has no effect on the amount of air required. The 7.1 pounds of oxygen renders one-eighth its weight of hydrogen inert, because it combines with that amount. The available hydrogen is, therefore, $H - \dfrac{0}{8} = 4.5 - \dfrac{4.5}{8} = 3.94$ pounds. The total combustible is 80 pounds of carbon + 3.94 pounds of hydrogen = 83.94 pounds total.

According to Table XVIII, the carbon will require $80 \times 2.67 = 213$ pounds of oxygen for combustion; the hydrogen, $3.94 \times 8 = 31.52$ pounds; and the sulphur, $.75 \times 1 = .75$ pounds, making a total of 245.27 pounds. To furnish this oxygen, $245.27 \times 4.32 = 1,059.57$ pounds of air will be required for the 100 pounds of coal, or $\dfrac{1,059.57}{100} = 10.6$ pounds of air per pound of the coal.

The number of pounds of air required per pound of any fuel may be obtained by the formula: $Air = 11.53C + 34.56H - 4.32O + 2.16S$, half the sulphur being assumed to be combustible.

Table XXI shows the theoretical amount of air

needed for the complete combustion of different types of coal. Since dry air at 62° F. weighs .0761 pound per cubic foot, the volumes corresponding to the weights of air given in Table XXI, may be found by dividing the weights by .0761.

The analysis of the different coals in Table XXI are taken from Table A, in the appendix, the coals that have the same sample numbers in the two tables being identical. A sample of both the lower and the higher grades of each type of coal appear in Table XXI, while the bituminous coal has, also, values for a middle grade of coal. The table shows that the lower the grade of a coal, the less air it requires for complete combustion. An inspection of the O and the ash columns will show that the reason for this lies in the increased amounts of oxygen and ash that the lower grades of coal contain. For example, each pound of peat, like sample 1, Table XXI, contains 51.69 per cent. of non-combustible oxygen and ash; hence, since there is less than ½ pound of combustible in the peat (42.46 per cent. of C and available H), only 5.33 pounds of air is necessary for each pound of peat. Sample 242 contains only 10.67 per cent. of O and ash, and 87.42 per cent. of C and available H. As the coal contains more than twice as much combustible as the peat, it naturally requires more than twice as much air for combustion. The air required for the combustion of a fuel, therefore, is in proportion to the percentage of C plus the available H per pound of fuel.

Air Actually Required for Combustion of Coal.— The theoretical quantity of air required for the combustion of coal is calculated on the assumption that each atom of oxygen of the air comes in contact and

unites with its proper proportion of carbon or hydrogen of the fuel; hence, that all the oxygen of the air combines with the fuel. This assumption is not true. As the oxygen must come in actual contact with the carbon and hydrogen in order to combine with them, it is evident that all the oxygen of the air cannot combine with the fuel and that some of it must pass through the flues and stack without having an opportunity of parting with its oxygen. The oxygen is diluted by four times its volume of nitrogen and by the products of combustion, so that both the nitrogen and the CO_2 of combustion must prevent some of the oxygen from coming in contact with the fuel. Also, the arrangement of the passages through the fuel is such as to allow considerable air to pass through the fire in streams, without parting with its oxygen. The varying resistance to the passage of air through the fire, owing to the irregular thickness of the fire on the grate and to lumps of coal, fine coal, clinker, ashes, etc., tends to prevent intimate contact of the oxygen and the fuel. If, however, just the theoretical quantity of air were to pass through the fire, it is evident that enough of its oxygen would not combine with the fuel to burn the fuel completely; therefore, the theoretical quantity of air must be increased by an amount that will be sufficient to furnish enough oxygen for complete combustion under furnace conditions.

Excess Air.—The amount of excess air that must be supplied for coal combustion varies with the draft, the kind of coal, and the method of firing the coal. As a general rule, the stronger the draft the less excess air will be required. For example, in hand-firing, a coal that theoretically requires 11 pounds of air per pound of fuel with a very weak

TABLE XXI.
Air Required for Combustion of Different Types of Coals.

Sample No.	Kind of Coal.	C.	H.	C + H.	Available $\frac{O}{8} = H$	S.
1	Peat................	40.78	5.55	46.33	1.68	.53
6	Peat................	51.18	6.06	57.24	1.77	.49
2	Lignite..............	44.11	5.57	57.24	1.44	3.95
19	Lignite..............	57.31	5.28	49.68	1.65	.71
2b	Subbituminous.......	48.65	4.45	62.59		.61
56	Subbituminous.......	64.01	6.18	53.10	3.48	.27
40	Bituminous..........	59.58	4.83	70.19	3.32	5.24
126	Bituminous..........	69.86	5.03	64.41	3.88	.62
245	Bituminous..........	82.65	5.15	74.89	4.41	.91
190	Semibituminous......	76.28	3.88	87.80	3.42	1.51
248	Semibituminous......	83.62	4.70	80.16	4.17	.66
179	Semianthracite.......	75.77	3.44	88.32	3.01	2.14
242	Semianthracite.......	82.06	4.35	79.21	4.07	1.24
	Anthracite...........	82.89	4.57	86.41 87.46	4.53	.68

Sample No.	N.	O.	Ash.	O. + Ash	Pounds of Air Required Theoretically Per Pound of Fuel	Pounds of Air Required Per Pound of Fuel, 50% Dilution	Pounds or Air Required Per Pound of Fuel, 100% Dilution
1	1.40	30.95	20.74	51.69	5.33	8.00	10.66
6	2.56	34.03	5.68	39.71	6.53	9.80	13.06
2	.55	33.07	12.75	39.71	5.66	8.49	11.32
19	1.06	25.83	9.81	45.82	7.35	11.03	14.70
2b	.85	38.57	6.87	35.64	5.53	8.30	11.06
56	.88	21.62	13.05	45.44	8.16	12.24	16.32
40	1.18	12.09	17.08	34.67	8.13	12.20	16.26
126	1.53	9.19	13.77	30.17	9.41	14.12	18.82
245	1.36	5.91	4.01	22.96	11.02	16.53	22.04
190	1.32	3.69	13.32	9.92	10.01	15.02	20.02
248	1.70	4.23	5.00	17.01	11.10	16.65	22.20
179	.53	3.47	14.65	9.23	9.82	14.73	19.64
242	1.68	2.26	8.41	18.12	10.89	16.34	21.78
	.64	1.09	10.13	10.67 11.22	11.14	16.71	22.28

natural draft may actually require from 22 to 28 pounds to obtain the best results—an excess of 100 per cent. or more.   Under the same conditions, but with a strong natural draft, the best results may be obtained with 20 to 24 pounds.   By reducing the grate surface and employing forced draft, the quantity of air required may be reduced to 18 pounds per pound of fuel, an excess of only 50 per cent. A stoker grate provides special advantages for the equable distribution of air to the fire, so that when a stoker is combined with forced draft the amount of excess air required is reduced to a minimum.

Table XXI shows that the combustible, $C + H$, of the coals given ranges from less than 50 per cent., sample 2, to more than 88 per cent., sample 248, while the non-combustible ranges from about 50 per cent. to about 12 per cent.   The more non-combustible a coal contains, the more difficult it is for the oxygen to come in contact with the combustibles; hence the greater the amount of excess air required to completely burn all the combustible.   The poorer grades of coal therefore require more excess air than good grades.

Effect of Improper Air Supply.—If insufficient air is supplied to the fire, some of the carbon is burned to CO instead of to CO_2 and the coal does not develop its full heat value.   This condition is always indicated by a lowering of the furnace temperature, as well as by the production of smoke with bituminous coal and by the amount of CO discharged from the stack with anthracite or coke.   On the other hand, a supply of air that is more than sufficient is a source of waste, also, because the extra air merely absorbs heat and carries a good portion of it out of

the stack. This results, also, in a reduction of the furnace temperature.

Heat of Combustion.—The quantity of heat generated by the combustion of carbon and of the hydrocarbon gases has been determined directly by means of careful, accurate calorimeter tests. The results of these tests, as measured by the number of B. T. U. that are given out on the combustion of 1 pound of each substance, are given in Table XXII.

TABLE XXII.

Heat Evolved by Different Combustibles.

Combustible 1 Pound of	Total Heat evolved in burning 1 Pound of Combustible, B. T. U.
Carbon to CO_2...........................	14,650
Carbon to CO...........................	4,400
CO to CO_2.............................	4,400
Carbon in CO (2.33 pounds CO) to CO_2..	10,250
Ethylene, C_2H_4	21,370
Methane CH_4	23,510
Acetylene, C_2H_2	21,460
Benzole Gas, C_6H_6.....................	18,184
Hydrogen	62,100
Sulphur	4,000

Table XXII shows that in burning 1 pound of carbon to CO_2, 14,650 heat units are produced, whereas, if 1 pound of carbon is burned to 2.33 pounds of CO, only 4,400 heat units are evolved. Therefore, for every pound of carbon incompletely burned, 14,650 — 4,400 = 10,250 heat units are lost. If the 2.33 pounds of CO is burned to CO_2, it will evolve 14,659 — 4,400 = 10,250 heat units. This shows that

the same amount of heat is evolved in burning 1 pound of C to CO_2, regardless of whether the carbon is burned to CO_2 at once or whether it is first burned to CO and the CO is then burned to CO_2. As the 2.33 pounds of CO evolve 10,250 heat units in burning, it is evident that 1 pound of CO evolves $10,250 \div 2.33 = 4,400$ B. T. U.

CHAPTER XIII

HEORETICAL Temperature of Combustion.—The heat evolved by the combustion of a substance is capable of heating the products of combustion to a temperature that depends on the weight and the specific heats of the products of combustion. Since the weight and the nature of the products of combustion differ for different fuels, the temperature due to the combustion of different fuels will vary; that is, the temperature of the fires will differ.

The theoretical temperature for combustion is the temperature that would result from the burning of a substance in the theoretical quantity of air, provided all possible losses were prevented. This temperature is calculated by dividing the number of heat units generated during the combustion of the substance by the sum of the weights of the gaseous products, multiplied by their specific heats, as given in Table XXIII.

The specific heat of air at ordinary temperatures is .2377. At high temperatures, it is known to increase considerably and is believed to approximate .3 for furnace temperatures.

Heat Absorbed by Products of Combustion.—The specific heat of a substance is the number of heat units required to raise 1 pound of the substance 1° F. For example, the specific heat of nitrogen, Table XXIII, is .245; this means that .245 unit of heat is required to raise 1 pound of nitrogen 1° F. in

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TABLE XXIII.

Specific Heats of Gases, H_2O at 32° F. 1.

Name of Gas.	Equal Weights		Equal Volumes.	
	At Constant Pressure.	At Constant Volume.	At Constant Pressure.	At Constant Volume.
Air between 32° and 392° F..	.2377	.1688	.2377	.1688
Air at furnace temperature (approx.)	.3000			
Oxygen	.2175	.1550	.2412	.1723
Nitrogen	.2450	.1740	.2370	.1690
Carbondioxide	.2170	.1535	.3308	.2620
Carbonmonoxide	.2479	.1758	.2399	.1711
Hydrogen	3.4046	2.4096	2.3560	1.6670
Methane	.5929	.4683	.3277	.2588
Ethylene	.3694	.2992	.3572	.2893
Gaseous steam at atmospheric pressure	.4805	.3460		
Sulphur dioxide.............	.1553	.1246	.3277	.2588

temperature. To raise 1 pound of nitrogen through 150° F., it requires $150 \times .245 = 36.75$ B. T. U. Hence, the heat absorbed by 10 pounds of nitrogen raised through 150° F. will be $10 \times 36.75 = 367.5$ B. T. U. Stated as a general rule for any of the products of combustion, the heat absorbed may be found by the formula:

$$h = 1 \times t \times S$$

in which, h represents the B. T. U. absorbed; l, the number of pounds of substance; t, the degrees Fahrenheit through which the products are superheated; and S, the specific heat of the substance.

Temperature Produced by Carbon.—In burning 1 pound of carbon to CO_2, 14,650 B. T. U. are gen-

erated, Table XXII, and the products of combustion, Table XVIII, are 8.86 pounds of N and 3.67 pounds of CO_2. To raise the temperature of the products of combustion 1° F., it requires:

	WEIGHT	SPECIFIC HEAT	B. T. U.
Nitrogen	8.86 ×	0.244 =	2.1618
Carbon dioxide	3.67 ×	0.217 =	.7964

Total B. T. U................. 2.9582

Therefore, the 14,650 B. T. U. will raise the temperature to 14,650 ÷ 2.9852 = 4,952° F.

To burn 1 pound of carbon to CO, 4,400 B. T. U. are generated, and 2.33 pounds of CO and 4.42 pounds of N are produced. To raise the temperature of the gases of combustion 1° F., it requires:

	WEIGHT	SPECIFIC HEAT	B. T. U.
Carbon monoxide	2.33 ×	.245 =	.57
Nitrogen	4.42 ×	.244 =	1.08

Total B. T. U..................... 1.65

The temperature acquired by the burning of 1 pound of C to CO will be 4,400 ÷ 1.65 = 2,666° F.

Burning 1 pound of CO to CO_2 generates 4,400 B. T. U. and produces 1.57 pounds of CO_2 and 1.89 pounds of N. To raise the temperature of the gases 1° F., it requires:

	WEIGHT	SPECIFIC HEAT	B. T. U.
Carbon dioxide	1.57 ×	.217 =	.34
Nitrogen	1.89 ×	.244 =	.46

Total B. T. U..................... .80

The temperature produced by the burning of CO to CO_2 will be 4,400 ÷ .8 = 5,500° F.

Temperature Produced by Hydrogen. — One pound of hydrogen, in burning, generates 62,100 B. T. U. and evolves 26.56 pounds of N and 9 pounds of H_2O. To raise the temperature of the products of combustion 1° F., it requires:

	WEIGHT		SPECIFIC HEAT		B. T. U.
Nitrogen	26.56	×	.244	=	6.48
Water	9.00	×	.48	=	4.32

Total B. T. U................. 10.80

Since the temperature of the water vapor is not reduced to the temperature of the atmosphere, the heat needed to raise the water from the temperature, t, of the atmosphere to 212° F. and to vaporize it at that temperature must be subtracted from the total heat value of the hydrogen. If t = 62° F., then to raise 1 pound of water to 212° F. it will require 212 — 62 = 150 B. T. U., and to evaporate the pound of water it will require 966 B. T. U., making a total of 150 + 966 = 1,116 B. T. U.; therefore, 9 pounds will require 9 × 1,116 = 10,044 B. T. U. The heat units of the hydrogen available for heating the products of combustion will be 62,100 — 10,004 = 52,056 B. T. U. Hence, since it requires 10.8 B. T. U. to raise the products of combustion 1° F., the temperature acquires by the burning of the hydrogen will be 52,056 ÷ 10.8 = 4,820° F. This temperature is practically equal to the temperature acquired by burning carbon to CO_2.

Temperature Produced by Methane.—One pound of CH_4 generates 23,513 B. T. U. and produces 2.75 pounds of CO_2, 1,328 pounds of N, and 2.25 pounds of H_2O.

	WEIGHT		SPECIFIC HEAT		B. T. U.
Carbon dioxide. 2.75	$\times$	.217	=	.597
Nitrogen 13.28	$\times$	.244	=	3.240
Water 2.25	$\times$	.480	=	1.080

Total B. T. U.................. 4.92

To raise 2.25 pounds of H_2O from the tempera-
ture, t, to 212° F. and evaporate it at that tempera-
ture, it requires $2.25 \times (212 - t + 966)$ B. T. U.
When t = 62° F., this will equal $2.25 \times 1,116 = 2,511$
B. T. U., so that the total effective B. T. U. will equal
$23,513 - 2,511 = 21,002$ B. T. U. Therefore, the
temperature produced by burning CH_4 will be 21,002
$\div 4.92 = 4,269°$ F.

Temperature Produced by Ethylene.—One pound
of C_2H_4 generates 21,370 B. T. U. and produces 3.14
pounds of CO_2, 11.39 pounds of N, and 1.29 pounds of
H_2O.

	WEIGHT		SPECIFIC HEAT		B. T. U.
Carbon dioxide 3.14	$\times$	.217	=	.68
Nitrogen 11.39	$\times$	.244	=	2.78
Water 1.29	$\times$	.48	=	.62

Total B. T. U.................. 4.08

To raise 1.29 pounds of H_2O from the tempera-
ture, t, to 212° F. and evaporate it, where t = 62° F.,
$1.29 \times 1,116 = 1,439$ B. T. U. are required. There-
fore, the temperature of combustion of C_2H_4 will be
$21,370 - 1,439 \div 4.80 = 4,885°$ F.

Temperature Produced by Acetylene. — One
pound of C_2H_2 generates 21,460 B. T. U. and produces
2.24 pounds of CO_2, 10.19 pounds of N, and 1.83
pounds of H_2O.

	WEIGHT	SPECIFIC HEAT	B. T. U.
Carbon dioxide	2.24 ×	.217 =	.486
Nitrogen	10.19 ×	.244 =	2.486
Water	1.83 ×	.480 =	.878

Total B. T. U. 3.850

To raise 183 pounds of H_2O to 212° F. and evaporate it at that temperature, it requires $1.83 \times 1,116 = 2,042$ B. T. U., so that the total effective B. T. U. will equal $21,460 - 2,042 = 19,418$ B. T. U. The temperature produced will equal $19,418 \div 3.85 = 5,046°$ F.

Temperature Produced by Benzole.—One pound of C_6H_6 generates 18,184 B. T. U. and produces 2.24 pounds of CO_2, 10.19 pounds of N, and 1.83 pounds of H_2O. Since these quantities are the same as for C_2H_2, the total B. T. U. will be the same, or 3.85 B. T. U. The total effective B. T. U. will therefore equal $18,184 - 2,042 = 16,142$ B. T. U., and the temperature produced will equal $16,142 \div 3.85 = 4,193°$ F.

Temperature Produced by Sulphur.—One pound of sulphur in burning generates 4,000 B. T. U. and produces 3.32 pounds of N and 2 pounds of SO_2.

	WEIGHT	SPECIFIC HEAT	B. T. U.
Nitrogen	3.32 ×	.244 =	.81
Sulphur dioxide	2.00 ×	.155 =	.31

Total B. T. U. 1.12

Therefore, the temperature of combustion of sulphur will be $4,000 \div 1.12 = 3,571°$ F.

For convenience of reference, the theoretical temperatures of combustion are arranged in tabular form in Table XXIV.

TABLE XXIV.

Theoretical Temperature of Combustion in Air.

Combustible	Temperature of Combustion, Degrees F.
Carbon to CO_2..........................	4,952
Carbon to CO........................	2,666
Carbon monoxide to CO_2.............	5,500
Hydrogen	4,820
Ethylene, C_2H_4........................	4,885
Methane, CH_4.........................	4,269
Acetylene, C_2H_2.......................	5,046
Benzole, C_6H_6.........................	4,193
Sulphur to SO_2........................	3,571

These temperatures are the number of degrees F. that the heat of combustion can raise the products of combustion. The actual theoretical temperature of the fire would be found by adding the temperature of the atmosphere to the resulting temperature of combustion. Thus, with an atmospheric temperature of 0° F., the temperature developed by burning C to CO_2 would equal 4,852 F.; whereas, with a temperature of 100° F., the temperature developed would be $4,952 + 100 = 5,052°$ F. If the air were heated to 300° F., the temperature developed would be $4,952 + 300 = 5,252°$ F.

The theoretical temperatures are calculated on the assumption that only just sufficient air is supplied to furnish the necessary oxygen, and that all the oxygen unites with the combustible; also, that there are no losses through radiation or otherwise. In ordinary practice it is impossible to obtain the full theoretical temperature, owing to the fact that combustion is seldom complete; air in excess of the

theoretical amount is always supplied; the fuel is never entirely consumed; heat is lost by radiation in the ashes, in the stack gases, etc.; and the moisture in the fuel absorbs some of the heat. On account of such losses, the furnace temperature seldom reaches 3,000° F., and, usually, it is between 1,800° F. and 2,400° F.

Effect of Insufficient Air on Temperature.—

When insufficient air is provided to burn carbon completely, the carbon will be burned partly to CO and partly to CO_2, the resulting temperature depending on the amount of the deficiency, as given in Table XXV.

From Table XXV it will be observed that a 25-per-cent. reduction of the theoretical amount of air necessary to burn the carbon completely reduces the temperature to 4,196° F., while a 50-per-cent. reduction decreases the temperature of the fire to 2,666° F. This reduction of temperature is due to the reduction of the total heat generated by the coal, due to insufficient air.

TABLE XXV.

Effect of Insufficient Air Supply.

Air Supply, Pounds	Carbon Burned to		Heat Generated from		Total Heat, B.T.U.	Temp. of Comb., Deg. F.	Loss in Temp. Due to Insufficient Air, Deg. F.	B. T. U. Lost on Account of Insufficient Air.
	CO_2 Per Cent.	CO Per Cent.	CO_2 B.T.U.	CO B.T.U.				
11.53	100		14,650		14,650	4,952		
8.65	50	50	7,325	2,200	9,525	4,196	756	5,125
5.77		100		4,400	4,400	2,666	2,286	10,250

Cooling Effect of the Air Supply.—It has been shown that the temperature developed in completely burning fuel depends on the number of heat units per pound of fuel and on the amount and the nature of the products of combustion. It will also be shown that the amount of air supply during the burning of a fuel greatly affects the temperature developed. Air in excess of the theoretical amount must be supplied for the reason that, otherwise, the coal would not burn completely and generate its full heat value. Some of the air passes through the fire and out the stack without having an opportunity to part with its oxygen. If, therefore, only the theoretical amount of air were admitted to the furnace, it would not supply sufficient oxygen to burn the coal completely. Tests have demonstrated that when the air is properly admitted to the furnace, from 50 to 100 per cent. of excess air must be supplied, depending on the furnace and on the nature of the coal, in order to secure complete combustion. This excess air increases the amount of the gases of com-

TABLE XXVI.

Cooling Effect of the Air Supply.

Air Supply, Pounds.	Weight of Stack, Gases, Pounds.			Total Heat Generated by 1 Pound of Coal. B. T. U.	Temperature of Combustion. Degrees F.	Loss per Pound of Coal Heating Excess Air, B. T. U.	Loss in Temperature Due to Excess Air. Deg. F.
	Products of Combustion	Excess Air	Total.				
11.53	12.53		12.53	14,650	4,952		1,828
17.30	12.53	5.77	18.30	14,650	3,124	5,409	2,670
23.06	12.53	11.53	24.06	14,650	2,282	7,900	3,469
34.59	12.53	23.06	35.59	14,650	1,483	9,083	

bustion that must be heated by the coal; consequently, it reduces the temperature developed by the combustion, as shown in Table XXVI.

Table XXVI not only shows the loss in temperatures due to the air that passes through the furnace, but also shows, seventh column, the actual loss in B. T. U. due to the excess in air.

Heat Absorbed by Vapor in the Air.—Besides the direct loss due to the heat absorbed by the excess air during combustion, there is another loss due to heating the moisture that is contained in the atmosphere. It is to be remembered that the moisture in the atmosphere is mixed with the air and is not absorbed by the air. The statement is sometimes erroneously made that the air has a certain capacity for moisture, and the expression, saturated air is often seen. The presence of aqueous vapor, or moisture, in the atmosphere is entirely independent of the presence or the absence of air in the same space, except that the air retards the diffusion of the moisture particles. It is the space that contains moisture or is saturated with moisture, and not the air. Table XXVII gives the weight of vapor that is mixed with each pound of air for different temperatures. It will be seen that the capacity of space for moisture increases with the temperature, and doubles with each increase of about 20° F. The values given in the table are for 100-per-cent. saturations. For a saturation of less per cent., multiply the weight at 100-per-cent. saturation by the per cent. of saturation desired.

The moisture vapor in the atmosphere has to be heated from atmospheric temperature to 212° F., and superheated above that to the temperature of the

chimney gases, all this heat being carried out of the
stack and lost.

Example.—How much heat is lost on account of mois-
ture in the atmosphere in burning 1,000 pounds of coal hav-
ing a heat value of 12,500 B. T. U. and using 20 pounds of
air at 102° F., the humidity being 80 per cent. and the gases
of combustion escaping to the chimney at 550° F.?

Solution.—At 102° F., 1 pound of air at saturation has
.04547 pound of moisture mixed with it, Table XXVII, so that
1,000 × 20 = 20,000 pounds of air must be mixed with 909.4

TABLE XXVII.

Weight of Vapor in Atmosphere.

Degress F.	Weight, in Pounds, of a Cubic Foot of			Weight of Vapor in 1 Pound of Air Pounds
	Dry Air	Vapor	Air and Vapor	
0	.0863	.000079	.086379	.00092
12	.0840	000130	.084130	.00155
22	.0821	.000202	.082302	.00245
32	.0802	.000304	.080504	.00379
42	.0784	.000440	.078840	.00561
52	.0766	.000627	.077227	.00819
62	.0747	.000881	.075581	.01179
72	.0727	.001221	.073921	.01680
82	.0706	.001667	.072267	.02361
92	.0684	.002250	.070717	.03289
102	.0659	.002997	.068897	.04547
112	.0631	.003946	.067046	.06253
122	.0599	.005142	.065042	.08584
132	.0564	.006639	.063039	.11771

pounds of moisture. At 80-per-cent. saturation, the moisture
contained in the atmosphere will be .80 × 909.4 = 727.5
pounds. Raising 1 pound of moisture from 102° to 212° F.
will absorb 212 — 102 × 1 (the specific heat of water) = 110
B. T. U.; superheating 1 pound of moisture from 212° to
550° F. will absorb (550 — 212) × .48 = 162.24 B. T. U.

Therefore, heating 727.5 pounds of moisture from 102° to 550° F. will absorb $727.5 \times (110 + 162.24) = 198,040$ B. T. U. This represents the heat value of $198,040 \div 12,500 = 16$ pounds of coal, which is $\dfrac{198,040 \times 100}{12,500 \times 1,000} = 1.6$ per cent. of the heat value of the coal.

From Table XXVII, it will be seen that the amount of heat wasted through atmospheric moisture decreases with the temperature and with a decrease in the degree of saturation. Also, it depends on the temperature at which the products of combustion escape to the stack. In the above example, with 100-per-cent. saturation, the heat loss would be 19.8 B. T. U., or 1.98 per cent. of the heat value; whereas, with 60-per-cent. saturation, the loss would be only 9.9 B. T. U., or only .99 per cent. of the heat value.

Heat Loss Due to Moisture in Coal.—The loss due to moisture in coal is represented by the loss of coal displacement, by the loss of vaporization, and by the loss of superheating the steam to the chimney temperature. A coal contains $2,000 \times .01 = 20$ pounds of moisture per ton for each per cent. of moisture; hence, the loss through the water displacing coal amounts to 20 pounds of coal per ton for each per cent. of moisture. To raise 1 pound of water from 60° F. and vaporize it at 212° F. will require $(212 - 60) + 9,668 = 1,118$ B. T. U. Therefore, 20 pounds will require $20 + 1,118 = 22,360$ B. T. U. This would represent $\dfrac{22,360}{12,500} = 1.79$ pounds of coal for a coal having a heat value of 12,500 B. T. U. per pound. If the chimney temperature were 550° F., the vapor would be superheated $550 - 212 = 338°$; hence, the superheating would absorb

$20 \times .48 \times 338 = 3,245$ B. T. U., which equals $\frac{3,245}{12,500} = .26$ pounds of coal. The total loss for each per cent. of moisture in the coal, therefore, under the above conditions, would be $20 + 1.19 + .26 = 22$ pounds coal. If the coal contained 5 per cent. of moisture, the loss would equal $5 \times 22 = 110$ pounds of coal per ton of 2,000 pounds. This equals .55 per cent.

Loss of Temperature Through Decomposition.— When oxygen unites with a combustible in burning, heat is generated. To decompose the products of combustion after they have formed, the same quantity of heat must be absorbed by the compound as was generated by the union of the elements. For example, Table XVII, 1 pound of CO burning to CO_2 generates 4,400 B. T. U., and in decomposing this CO_2 into CO, and O, 4,400 B. T. U. will be absorbed. The air enters the bed of fire from below, so that the oxygen forms CO_2 with the carbon of the lower layers of coal. The CO_2 in passing through the upper layers of the fire is reduced to CO by taking up another part of the carbon, according to the reaction $CO_2 + C = 2CO$. If the CO meets more oxygen, it will burn to CO_2 again; otherwise, it will escape as CO. In combining to form CO_2, 14,650 heat units are generated. In the reduction of CO_2 to CO, 10,250 heat units are absorbed, leaving only $14,650 - 10,250 = 4,400$ B. T. U. as a final result of the combination.

In burning 1 pound of hydrogen, 9 pounds of water vapor is formed by the chemical combination of oxygen with the hydrogen, Table XVIII. This generates 62,100 B. T. U. If 9 pounds of moisture in

the coal were decomposed into hydrogen and oxygen, it would absorb 62,100 B. T. U. from the fire, thus reducing the heat value of the coal that amount. Every 9 pounds of moisture in the coal that is decomposed by the heat of the furnace, absorbs as much heat as 1 pound of the available hydrogen of the coal can develop.

DETERMINING THE HEAT VALUE OF COAL

DULONG'S Formula.—The heating value of a coal is usually determined directly by burning a sample of the coal in a calorimeter. It may, however, be calculated from the ultimate analysis of the coal by means of Dulong's formula, which is:

$$\text{B. T. U.} = 14{,}600C + 62{,}000\ (H - \frac{O}{8}) + 4{,}000S,$$

in which the carbon, **C**, hydrogen, **H**, oxygen, **O**, and sulphur, **S**, are expressed in per cent. By dividing the quantities on the right of the equation by 100, the formula becomes:

$$\text{B. T. U.} = 146C + 620\ (H - \frac{O}{8}) + 40S,$$

in which C, H, O, and S are the percentages of the quantities in the coal.

EXAMPLE.—What is the heat value, per pound, of a coal containing 4.45 per cent. of S, 4.97 per cent. of H, 70.45 per cent. of C, 5.5 per cent. of O, and 13.64 per cent. of ash?

SOLUTION.—Substituting in the formula, B. T. U. = $146 \times 70.45 + 620 \times (4.97 - \frac{5.5}{8}) + 40 \times 4.45 = 13{,}117$ B. T. U.

Unit Coal.—The difficulty of comparing coals for commercial purposes of Dulong's formula lies in the fact that an ultimate analysis of the coal is necessary in order to determine the per cent. of carbon and hydrogen in the coal. The hydrogen is a variable, and its exact amount is difficult to determine. Also, the formula does not differentiate between the combustible organic matter of the coal

and the inert or non-combustible mineral constituents. In the comparison of coals, it is very important that the formula used take these into account, so that the coals may be compared as free from extraneous matter, such as moisture, ash, and sulphur.

Through the investigations of Prof. S. W. Parr of the University of Illinois, and his first assistant, Mr. W. F. Wheeler, it was found that the ordinary methods of analysis do not take proper account of the water of hydration of the shaly or clayey portions of the ash, or of the carbon-dioxide content of the earthy carbonates. These non-coal constituents are driven off as a volatile at red heat and are therefore included as part of the volatile combustible of the coal instead of as part of the ash. For example, suppose the shaly or clayey content of the ash contains 8 per cent. of combined water. The ordinary method of analysis will drive off this water of hydration and will include it with the volatile combustible instead of with the ash; hence, the correct fuel value of the coal is not obtained. Gypsum would produce a like inaccuracy on account of its water of crystallization being included with the volatile combustible matter. Also, calcium carbonate would loose carbon dioxide in the process of analysis that would induce an inaccuracy similar to the above.

Before making the proximate analysis, the coal should be tested with acid so as to liberate the CO_2, which should be measured by weight or by volume. If the CO_2 is more than 3 per cent. or the $CO_2 + Cl$ is 5 per cent. or more, the ash determination of the analysis should be made by blasting in a platinum crucible to a constant weight; to the weight of the ash must then be added the weight of CO_2 found.

Also, since the heat will drive off any chlorine, Cl, that may be present, the amount of Cl should be determined and also added to the weight of the ash.

To account for the moisture, M, sulphur, S, and ash, and to correct for the water of hydration and for similar impurities in the ash, Parr and Wheeler propose the following formula for comparing the heat values of coals and for classifying them according to their per cent. of combustible or coal content, and non-coal or mineral content. By the use of this formula, the coal is reduced to actual, or unit, coal, the term unit coal meaning coal free from ash, moisture, pyrites, and volatile organic matter.

For coals that are dry and free from carbonates and chlorides, use the formula:

$$\text{B. T. U.} = \frac{\text{indicated B. T. U. for dry coal} - 5{,}000\text{S,}}{1.00 - (1.08 \text{ ash} + 22/40\text{S})}$$

The formula for calculating the heat value for coal based on wet coal values is:

$$\text{B. T. U.} = \frac{\text{indicated B. T. U. for wet coal} - 5{,}000\text{S}}{1.00 - (\text{M} + 1.08 \text{ ash} + 22/40\text{S})}$$

By indicated B. T. U. is meant the heat value of the coal that is obtained from a proximate analysis.

Table XXVIII gives a comparison of results obtained from analyses made in the ordinary manner and from calculations by means of Parr and Wheeler's formula. The values per pound of combustible obtained by the former method are lower and vary more than the values obtained for unit coal.

The B. T. U. per pound of combustible is found as follows: From the first volumes in Table XXVIII, the non-combustible is equal to $12.92 + 16.58 + 3.82 = 33.32$ per cent.; therefore, the 9,992 B. T. U. represent only $1 - .3322 = .6678$ per cent. of combustible. The total inorganic matter of the coal is rep-

TABLE XXVIII.

Heat Values of Unit Coal.

Analyses of Samples Received					B. T. U. Per Pound of Unit Coal, Calculated
Moisture	Ash	Sulphur	B.T.U.Per Pound of Coal	B.T.U.Per Pound of Combustible	
12.92	16.58	3.82	9,992	13,311	14,613
14.22	18.16	4.51	9,540	13,059	14,624
12.45	17.22	4.14	9,950	13,314	14,608
23.00	19.48	4.31	9,501	12,996	14,601
12.08	17.13	3.67	10,160	13,500	14,801
12.67	16.90	4.26	10,062	13,466	14,757
12.71	16.79	4.22	10,071	13,467	14,752
12.36	18.80	5.17	9,801	13,362	14,794
12.36	16.53	5.07	10,170	13,624	14,800
12.70	15.20	3.89	10,269	13,534	14,655

resented in the formula by $M + 1.08\ A + 22/40\ S$, M representing the moisture and 1.08 A the ash and the volatile inorganic constituent, the 8 per cent. being an arbitrary factor representing the latter; the ash as weighed is corrected for the iron pyrites, FeS_2, burned to Fe_2O_3 by substracting from the ash the factor 22/40 S, which is 22/40 of the weight of the sulphur, as determined. Hence, if .6678 pound of combustible = 9,992 B. T. U., 1 pound will equal $1.3322 \times 9,992 = 13,311$ B. T. U.

The B. T. U. for unit coal is calculated as follows:

$$B.\ T.\ U. = \frac{9,992 - 5,000 \times .0382}{1 - (.1292 + 1.08 \times .1658 + \frac{22}{40} \times .0382}$$

$$= \frac{9,992 - 191}{1 - (.1292 + .1791 + .0210}$$

$$= \frac{9,801}{1 - .3293} = \frac{9,801}{.6707} = 14,613\ B.\ T.\ U.$$

It will be noted that the values of M, S, and ash in these formulas are expressed in per cent.   To avoid this, the formulas have been reduced to the following forms:

$$\text{B. T. U.} = \frac{100 \times \text{indicated B. T. U.} - 5000S}{100 - (1.08A + \frac{22S}{40})}$$

$$\text{B. T. U.} = \frac{100 \times \text{indicated B. T. U.} - 5000S}{100 - (M + 1.08A + \frac{22S}{40})}$$

Calculating the B. T. U. for unit coal for the above case with this formula,

$$\text{B.T.U.} = \frac{100 \times 9{,}992 - 5{,}000 \times 3.82}{100 - (12.93 + 1.08 \times 16.58 + \frac{22}{40} \times 3.82)}$$

$$= \frac{999{,}200 - 19{,}100}{100 - 32.93} = \frac{980{,}100}{67.07} = 14{,}613 \text{ B. T. U.}$$

CHAPTER XV

FURNACE Conditions.—In burning coal, two factors must be considered—the burning of the volatile ingredients and the burning of the fixed carbon. When fresh coal is thrown on a fire, it begins at once to absorb heat. This heat performs two functions: It does internal work in volatilizing and driving out the gaseous content of the coal, and it raises the temperature of both the fixed carbon and the gases. This absorption of heat cools the temperature of the furnace. When the temperature of the fuel is raised to between 700° and 900° F., the pitch, tar, naphtha, etc. of the coal begins to be driven off, and they continue to be produced until the fuel is at a temperature of about 1,800° F., when practically all are driven off. These constituents of the coal will not burn as tar, etc., but must be heated until they pass into the gaseous state and are broken up into their elements. They constitute a rich, smoky volatile that is produced at moderate temperatures, and, in burning, they will make much dense, black smoke unless conditions are favorable for their smokeless combustion.

The hydrogen, Fig. 4, does not volatilize freely below a temperature of about 1,300° F., but above that temperature it is driven off rapidly and uniformly until the temperature of the coal reaches about 1,800° F., when it is practically all distilled.

The fixed carbon of bituminous coal begins to

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burn at a red heat, about 800° F., Table XX; where-
as, the gases under furnace conditions do not begin
to burn until their temperature exceeds 1,400° F.
Thus, both the fixed carbon and the gases absorb
heat from the fire in the beginning, and this reduces
the furnace temperature and is one reason why the
steam pressure drops when a heavy charge of coal is
fired at one time. Also, it may reduce the furnace
temperature to a point where the tars and vapors
which are first to be liberated and at the lowest tem-
peratures, will produce much smoke. A sufficiently
high furnace temperature is absolutely necessary to
promote the vaporization of the tar and vapors, and
the ignition and complete combustion of the gases of
the coal. Where the temperature is below their
igniting points, the gases will escape unburned, and
the burning of the fixed carbon alone will be all that
produces heat in the furnace. Thus, a large percen-
tage of the heat value of the coal will be wasted.

If, when first liberated, the gases are mixed
with a sufficient quantity of air at the proper tem-
perature, they will be completely burned in the
form of a flame. The length of the flame will depend
on the furnace temperature, the quantity of the
combustible volatile matter to be burned, and on the
amount and the distribution of the air in the fur-
nace. Coals, like anthracite, with but little volatile
gases, burn with a short, transparent, blue flame.
Bituminous coals with sufficient air burn with a
longer, yellow, smoky flame. When the supply of air
above the fire is restricted, the flame becomes longer
and more smoky than it would be with sufficient air.

If a large volume of cold air passes through the
furnace in a solid stream, as when the firedoor is
opened wide, the gases surrounding the stream of

cold air are liable to be cooled below their igniting temperature and pass off unburned.

When the gases are heated to the igniting temperature in a restricted supply of air, carbon is liberated, or disengaged, in the form of a very fine powder, called soot. This soot, or carbon, floats in the gases at a white heat and thus gives luminosity to the flame. As soon as this carbon comes in contact with oxygen from the air, it unites and burns. Should it become cooled below its igniting temperature before it comes in contact with a supply of oxygen, it will pass off as free carbon, or soot, thus coloring the gases of combustion and forming smoke. These particles of incandescent free carbon are what give the color and most of the luminosity to the flame of illuminating gas.

Regulation of Air Supply.—To burn coal properly in a furnace, the furnace temperature must be high enough to volatilize the oils and tars quickly and to ignite the gases; the air supply must be just sufficient to furnish enough oxygen to burn the fuel constituents of the coal completely, it must be introduced into the firebox in small streams, so that it will heat quickly to the required temperature, and it must be intimately mixed with the volatile gases, so that its oxygen can come in actual contact with the combustible to the fuel and burn the combustible before it comes in contact with the boiler tubes. If all these conditions are not fulfilled, it will result in incomplete combustion, in loss of part of the gases, and probably in the production of smoke.

Tables XVIII and XX show that there will be a loss of furnace temperature and of fuel if the air supply is either too little or too much for the coal used. The calculations tabulated in Table XXI show

that the air required per pound of coal depends on the composition of the coal, on the amount of air that must be supplied in excess of the theoretical amount, on the condition and the thickness of the fire, and on the strength of the draft. The amount of air used should be just sufficient to develop the full heating power of the coal.

Admission of Air Supply.—The best method of admitting air to the furnace depends on the kind of coal that is being burned. In burning coal that is very low in volatile, like anthracite or semianthracite, the air for combustion can be admitted through the grates. For coals high in volatile, the air must be admitted so as to burn both the coke or fixed carbon on the grates and the volatile gases. Most of the air for burning the coke can be admitted through the grates, but the air for burning the gases and the upper layers of coal must be supplied above the fire. Carbon dioxide, CO_2, is indecomposable by heat alone, but it may be decomposed by contact with bodies avid of oxygen. Carbon at red heat will decompose CO_2, reducing it to CO. This reaction always takes place in a furnace. The air in passing the grates gives up its oxygen to form CO_2 with the carbon of the lower layers of coal, generating the full heat value of this union. The CO_2, which is at a very high temperature, moves upwards and comes in contact with the red-hot coke and unites with another atom of carbon in passing through the upper layers of the fire, being decomposed to CO and absorbing heat thereby. The CO passes up through the bed of the fire until it comes in contact with oxygen and burns, and if there is not a sufficient supply of oxygen to unite with it and burn it to CO_2, the CO will pass out of the stack unburned. To prevent this loss, and to insure suffi-

cient oxygen to burn the hydrocarbon gases as they are liberated from the coal, air must be suplied above the fire at such times as the gases are liberated in large volumes. Also, some provision should be made to control this air supply, so that, after a fire has been put in, the air can be diminished as the volume of gases liberated is diminished. If this provision is not made, an excess of air will be admitted after all the gases have been volatilized. The coke remains on the grates until burned, but the gases are in the furnace only a fraction of a second; so, to prevent their loss, conditions for burning them must be most favorable.

Air for the combustion of the gases should be admitted above the fire in fine streams, and provision should be made to insure a thorough mixing of the air and the gases while they are in the combustion chamber. Large currents of cold air cool the furnace temperature and allow the gases to escape unburned. This cooling effect of large streams of air is often taken advantage of by firemen when they open the firedoor to prevent the boiler safety valve from popping. The air admitted through the firedoor does not mix with the gases, but forms through the furnace a distinct current of cold air that chills the surrounding gases below their igniting temperature and they pass off unburned.

CHAPTER XVI

SMOKE AND ITS PREVENTION

FORMATION of Smoke.—Smoke consists of water vapor and the gaseous products of combustion, colored with fine particles of carbon or soot and with unburned vapors of the tarry constituents of the fuel. Therefore, if the soot and the unburned tarry vapors can be prevented from escaping to the stack, the products of combustion will be colorless, and there will be no smoke.

Smoke From Soot.—The soot of the smoke is not derived from the fixed carbon of the coal, which burns smokelessly, but from the tars and the volatile matter, the illuminants, and the heavier hydrocarbons, such as ethylene, C_2H_4, acetylene, C_2H_2, and benzole, C_6H_6. Coals rich in these constituents, especially when the gases distil rapidly at low and medium temperatures, will smoke badly, unless burned under conditions very favorable to smokeless combustion. On the other hand, coals low in illuminants and higher hydrocarbons will give no trouble from smoke under ordinary conditions of operation. If, when fresh coal is thrown on the fire, the gases as they are driven off are intimately mixed with the proper amount of air at a sufficiently high temperature, they will be completely burned and no smoke will be formed, provided the furnace is suited to the kind of coal that is being burned. If it is a high-volatile coal and sufficient air is not present and intimately mixed with the gases to burn all the large

volume given off, the hydrogen will combine with its portion of oxygen before the carbon will combine. For example, in insufficient oxygen, ethylene, C_2H_4, burns according to the equation $C_2H_4 + 2O = 2H_2O + 2C$. The hydrogen takes its full portion of the oxygen first, and the carbon combines with any that may be left. If none remains, all the carbon escapes as free carbon, or soot.

If, while on its way to the tubes, the free carbon comes in contact with oxygen and it is at its igniting temperature, the carbon and oxygen will unite and burn; otherwise, the carbon will be cooled, and when it strikes the tubes it will pass out of the stack as soot. The greater the deficiency in the air supply, or the less intimately the air is mixed with the gases, the more soot will escape and the blacker will be the smoke from this source. Therefore, to avoid the formation of smoke from soot, the volatile gases as they are liberated must be intimately mixed with a sufficient supply of air while at a temperature high enough to insure combustion, and the gases be completely burned before they enter the tubes. If the air supply is insufficient, if the air and gases are not intimately mixed, if the temperature is not high enough, or if there is not sufficient time in which to burn, smoke will result.

Flame.—The flame seen in the furnace is produced by the burning of the volatile gases of the fuel. Where a fuel, like coke, has no combustible volatile content, it will burn without flame unless furnace conditions are such that CO is formed, when a short, non-luminous flame will be produced. Anthracite coal burns with a very short, bluish flame, due to low volatile content; whereas, the flame from bituminous coals varies in length from a couple of

feet to 20 feet, depending on the nature and the amount of the volatile content and on the air supply. The length of the flame, therefore, indicates in a measure the liability of a coal to produce smoke. The color and luminosity of a flame, whether a gas-light flame or the flame in a furnace, is chiefly due to free particles of carbon at a white heat that are floating in the body of the gas. Where the carbon of the gases unites with oxygen at the instant that the carbon is liberated from the hydrocarbons, as in a Bunsen burner, there is no incandescent free carbon suspended in the gas. The flame, therefore, looses its light-giving properties and produces simply a very feeble, bluish light, due to the luminosity of the gas produced by its temperature. As the flame of anthracite is short and has but little color, it indicates a low-volatile content, and that a sufficient supply of air is mixed with the gas to burn the carbon as it is liberated from the hydrocarbons, which, in anthracite, consists chiefly of methane, CH_4.

The flame from bituminous coal varies, according to furnace conditions, from an intense, dazzling white to a dark, smoky, yellow. The intense, white-colored flame is comparatively short and indicates a high furnace temperature and good air supply, since the maximum flame temperature is obtained by burning a maximum quantity of gas in a minimum volume of flame. A dark, smoky flame is a long flame; it indicates very rich hydrocarbons, a restricted air supply, or a poor mixture of air and gases, and a comparatively low furnace temperature, a condition favorable to the production of large volumes of dense, black smoke. Thus, both the length and the color of the flame are an indication of the completeness of combustion of the gases.

Experiments in Smoke Production. — A few simple experiments will illustrate clearly the conditions that lead to the production of smoke from soot. The laws of combustion are the same whether applied to a furnace, a lamp, a candle, a gas jet, or a gas stove flame; hence, laws that apply to any one of these, apply to all.

Pour kerosene oil into a plate and set fire to it; dense, black clouds of smoke will rise, due to lack of sufficient air properly mixed with the gases to burn the oil completely over the whole surface.

A candle having a small wick produces a clear, bright light without smoke. A candle having a large wick has a dark, yellow-colored flame that has a tendency to smoke and does not give as bright a light as the candle with the small wick. The big wick tends to supply more oil than the conditions of the air supply warrant.

A torch has a still larger wick, since it is intended to burn a larger supply of oil. It smokes badly because the wick supplies more oil than can be burned smokelessly under the conditions of air supply.

These examples show that there is a limit to the quality of oil that can be burned smokelessly as a naked light. Consequently, to obtain more light than the candle would give, the kerosene lamp was invented. One reason for the torch smoking is that the wick is so thick that the air supply cannot intimately mix with the gas from the oil brought up through the center of the wick. To obviate this in the lamp, a wide, flat wick is used. Also, a chimney is employed to increase the air supply and to direct a current of air upwards and against the flame, thus insuring a sufficient air supply to burn the increased

amount of oil and give a clear, white light. If the chimney is removed, the flame will smoke, since there is nothing to create a current of air and direct it against the flame; hence, the air supply is deficient. The student's lamp with its circular burner permits the largest size of wick to be used, and since the air through the center of the tube is heated before coming into contact with the gases, the burner is well suited to give perfect combustion where a large amount of oil is being burned.

This discussion shows that, in order to have smokeless combustion, the air supply must be sufficient, and must be intimately mixed with the gases of the fuel while at the proper temperature; also, that the furnace must be suitably constructed to burn the required supply of fuel. A candle will give perfect satisfaction for the consumption of a small amount of oil, but an Argand burner is necessary to burn a large supply of oil satisfactorily.

Every lamp has a range through which it will burn smokelessly, but, without exception, if the range be exceeded, and the wick turned up so far as to supply more oil than can be burned perfectly, the lamp will smoke. This shows that if an attempt is made to burn more fuel in a furnace than the furnace is designed to burn, smoke will result.

Turn up the flame of a lamp until it produces a clear, bright light, indicating perfect combustion. Gradually close the draft openings at the base of the burner, and watch the flame. As the air supply is diminished, the flame gradually lengthens and becomes darker and darker, until, finally, it begins to smoke; then, if the air is still further restricted, the smoke increases, and when the flame extends above the chimney a stream of dense, black smoke arises

from the flame. The effect will be the same whether the air supply is restricted at the burner or at the top of the chimney, the amount of smoke produced being in proportion to the restriction of the air supply.

This experiment shows the effect of a restricted air supply on the flame and on the smoke produced. The effect will be the same whether the air supply is cut down below the requirements of the fuel, or the fuel supply is increased above the capacity of the air supply.

The flame of a gas stove when properly adjusted is short and produces a feeble, bluish light, similar to that of a Bunsen burner. Gradually restrict the air supply, and the flame will gradually lengthen and give off less and less heat; when the air supply is restricted too far, the flame will assume a dark-yellow color and will smoke, owing to the particles of free carbon that the restricted air supply allows to escape unburned. Note the time necessary to boil a quart of water from the same temperature, first, when the flame of the gas stove is short, due to a proper air supply, and second, when the flame is long and yellow, due to a restricted air supply; the short flame will be found to give a great deal more heat than the long flame, since it utilizes all the heat of the gases.

Turn the wick of a lamp up until the flame burns brightest, and remove the chimney. The flame will smoke badly. The oil from the wick is converted into a gas by the heat of the flame and if the gas were mixed with air in the proper proportions, a very hot, non-luminous flame would result, similar to that of a Bunsen burner. The luminosity of the lamp flame is due to the fact that the air does not penetrate

within, and mix with, the gas supply. The air
simply envelops the flame so that all the combustion
is on the surface of the gas supply. As the oil is
vaporized, it becomes heated and the hydrocarbons
are dissociated. The free carbon floating in the gas
supply is then heated to a white heat and travels to
the surface of the gas, where it combines with oxy-
gen and burns smokelessly. The chimney produces
a current of air and deflects it against the flame, thus
intimately mixing the air and the gas at the source
of the flame. When the chimney is removed, the
means of producing sufficient air for the gas and of
intimately mixing the air and the gas is absent;
hence, a smoky flame results.

A gas-light burner tip is designed so to spread
the flame as to give complete combustion with full
luminosity. Remove the tip so that the gas issues
from a round orifice, and a long, very smoky flame
will result, because the air is not intimately mixed
with the gas, and more time and space are needed
for the burning of the gas.

These examples indicate the importance of an
intimate mixture of sufficient air with the gaseous
content of coal, in order to obtain complete combus-
tion and to generate the maximum quantity of heat
from the gas without smoke.

Lower a pan of cold water into the flame of a
candle that is burning brightly without smoking,
and the flame will smoke badly, owing to particles of
free carbon in the flame coming in contact with the
cold metal and being chilled before they can burn.
This illustrates why a furnace smokes badly when
the heating surface is arranged so that the flames
can come in contact with it.

A pan of cold water placed on a gas-stove flame

does not cause smoke, because the burner mixes the air and the gas before they reach the flame; hence, the carbon of the gas is completely burned as it is dissociated and there are no free particles of carbon in the gas to produce smoke when the pan cools the flame.

Once a flame starts to burn, the heat produced by the combustion of the gas is sufficient to maintain the phenomenon of burning. If the flame is suddenly cooled at any point, the combustion beyond that point is at once arrested. A fine wire gauze held midway in a gas flame will cool the flame, since the incandescent gas cannot pass through the meshes of the gauze without being cooled below the igniting temperature by contact with the metal, which is a good conductor of heat. Hence, no combustion takes place above the gauze, although smoke is produced and the unburned gas passes through freely. If the gas above the gauze is ignited, it will burn. Also, if the gauze is held in a jet of gas that is escaping unlighted, the gas above the gauze may be burned without the gas below the gauze igniting.

These experiments show that if the combustion chamber of a furnace is not of sufficient capacity to prevent the flame from coming in contract with the cool surfaces of the boiler, dense, black smoke is sure to result.

Prevention of Soot.—From what has been said it will be seen that in order to prevent smoke from being formed from soot, and the following rules must be observed:

1. Sufficient air must be supplied to burn all the gases of the fuel completely.

2. The air must be intimately mixed with the

gases, so that each particle of gas is surrounded with air.

3.   The temperature of the air and the gases when they mix must be at or above the igniting temperature of the free carbon; otherwise, the carbon will escape as soot.

4.   If the carbon is cooled below its igniting temperature before coming in contact with a sufficient supply of oxygen, it will not burn and will escape as soot.   Therefore, the combustion chamber must be of sufficient volume for all the gas to burn before it reaches the tubes.   This is indicated by the flames not reaching the tubes.

Volatile Matter and Smoke.—The volatile matter of coals consists of light hydrocarbons, as methane; of tarry vapors, illuminants, and other heavy hydrocarbons, as ethylene, ethane, benzole, etc.; and of inert, non-combustible material, as carbon dioxide, and water vapor.   All coals do not have the same per cent. of these constituents, and the behavior of a coal in burning depends on both the character and the quantity of the volatile matter evolved in its heating.   The older bituminous coals of the Appalachian region give off an abundance of volatile rich in tarry vapors and in hydrocarbons that are difficult to burn smokelessly without proper combustion space and without special attention being given to the firing, the air supply, and the furnace temperature.   The younger subbituminous and lignite Western coals, while high in volatile, include a large portion of CO_2 and water vapor; hence, they do not tend to cause excessive smoke unless burned at high rates of combustion.   The bituminous coals of Indiana and Illinois are inter-

mediate types that, with care, can be burned without objectionable smoke within the capacity of the furnace. Thus, the smoke-producing tendency of coals does not depend so much on the relative total quantity of volatile matter of the coals as on the comparative richness of their volatile in hydrocarbons, and on the relative ease with which the volatile is set free at moderate temperatures. The heavy hydrocarbons in the tar and in such gases as ethylene, C_2H_4, acetylene, C_2H_2, benzole, C_6H_6, and others are the hardest to burn smokelessly, as they are slow-burning and require a large air supply intimately mixed with the gas.

TABLE XXIX.

Air Required by Carbon and by Hydrocarbons.

Combustible	Total Air, cu. ft.	Excess above Carbon, cu. ft.	Air required by H, cu. ft.	Air required by C, cu. ft.	Weight in 1 pound of Combustible, lbs.	
					H	C
C to CO_2.....	152	0	0	152	0	1
C to CO	76	76	0	76	0	1
CO to CO_2....	32	126	0	32	0	3/7
Hydrogen	454	302	454	0	1	0
Methane	227	75	113	114	1/4	3/4
Ethylene	195	43	65	130	1/7	6/7
Acetylene	175	23	35	140	1/13	12/13
Benzole	175	23	35	140	1/13	12/13

Table XXIX gives the total air, in cubic feet, required theoretically to burn 1 pound of the combustibles shown, as well as the proportions required by the hydrogen and the carbon in each case. The hydrogen always burns first and takes its air from the total air supply, leaving a greatly reduced

amount for the carbon, which burns last. As will be seen, 1 pound of methane consists of $\frac{1}{4}$ pound of H and $\frac{3}{4}$ pound of C; it requires a total of 227 cubic feet of air, of which the hydrogen takes half, leaving only 114 cubic feet for the $\frac{3}{4}$ pound of carbon. If only 152 cubic feet of air were supplied per pound of methane, only 38 cubic feet would be left to burn the $\frac{3}{4}$ pound of carbon. The hydrocarbons require so much more air than carbon or carbon monoxide that it is easily seen how a restricted air supply will liberate large quantities of carbon in the form of soot, and form smoke.

Smoke from Tarry Vapors.—In the manufacture of coal gas for illuminating purposes, the coal is placed in a retort from which the air is excluded and is gradually heated until all the volatile content is driven off. Besides the gas and the coke that is obtained from this process, a tar or black pitch is distilled as a liquid vapor and condensed into the solid form known as coal tar.

When a coal rich in tarry content is thrown onto a fire, the tar is distilled off in the form of a dark-colored liquid vapor, just as it is during distillation for illuminating gas. The process of distillation of the tar vapor is much the same as the distillation of water vapor that issues from the spout of a boiling kettle. If these tarry vapors escape unburned, they color the products of combustion and in this way form smoke.

If a piece of cold iron is thrust into the stream of volatile gases from a coal rich in heavy hydrocarbons and withdrawn before the iron becomes heated, some of the globules of tarry vapor will have condensed on the iron and will be seen to be a thick,

black liquid having a strong odor of coal tar. Every fuel gives off more or less tarry vapors, but the tar vapor from each fuel has a distinctive odor. It is owing to this fact that different kinds of wood in burning can be distinguished by their odor.

A coal rich in tarry vapors is a persistent smoke maker, owing to the difficulty with which the vapor is gasified and burned. The vapor is a liquid in the form of mist of minute tar globules, and these globules must first be converted into gas and then dissociated before they combine with the oxygen and burn. As each globule must be furnished with sufficient heat for gasification and for dissociation, as well as for raising the temperature of the gas to its igniting temperature, the process of burning may require more time than is afforded the vapor in passing from the fire to the tubes, in which event, the vapor will pass off as smoke. To burn tarry vapors successfully, a large combustion chamber and a sufficiently high furnace temperature, together with an adequate supply of air intimately mixed with the vapor, are imperative, because the vapor is comparatively slow-burning and requires a large supply of air.

Rate of Distillation of Volatile, and Smoke.— Laboratory experiments by Porter and Ovitz show that the quantity and the quality of volatile distilled from a coal depends largely on the rate at which the coal is heated. With a slow rate of heating, the volatile driven off is of gaseous composition, comparatively small in quantity, and contains only a small amount of tarry vapors. With a very rapid rate of heating, the volatile is high in quantity and contains a large amount of tarry vapors. When the hydrogen is distilled slowly from the coal, it takes

only a small quantity of carbon with it in the form of light hydrocarbons or easily burning gases, most of the carbon being burned on the grate as fixed carbon. When distilled off rapidly, the hydrogen takes a large amount of carbon with it in the form of heavy hydrocarbons, such as ethylene, ethane, benzole, etc., and of tarry vapors, leaving a smaller quantity of fixed carbon on the grate.

The fixed carbon is easily burned, because it remains on the grates until completely consumed. The hydrogen and the light hydrocarbons are easily burned, because they are quick-burning gases that have ample time to burn while in the combustion chamber of the furnace. The tarry vapors and the higher hydrocarbons are hard to burn, because they are slow-burning, and unless special provision is made for burning them, they usually pass out of the furnace before they have time to burn. It is very possible that the combustion of hydrogen and carbon monoxide consists of but a single reaction, whereas the combustion of the heavy hydrocarbons may consist of a series of reactions, thus lengthening somewhat the time required for their complete combustion.

The tarry vapors are very dark and make a dense, black smoke. Throw a small piece of coal tar on the fire and note the quantity and the color of the tarry vapor that arises from it; in this way the power of the tarry vapors to color the smoke will be readily understood. Thus may be seen the reason why a coal that gives off clouds of dense, black smoke when hand fired in an ordinary furnace burns smokelessly under the coking system of hand firing, or, when a proper mechanical stoker is used. In hand firing, the coal is thrown directly onto the fire and is

heated through a range of about 2,000° F. in from 2 to 3 minutes; whereas, in the coking method of hand firing, or when a well-operated chain-grate stoker is used, it may take from 15 to 20 minutes for the coal to heat through the same temperature range of 2,000° F. Mechanical stokers are designed to feed the coal into the furnace gradually; consequently, the rate of heating the coal is slow and conducive to smokeless combustion.

It has been pointed out that the tendency of
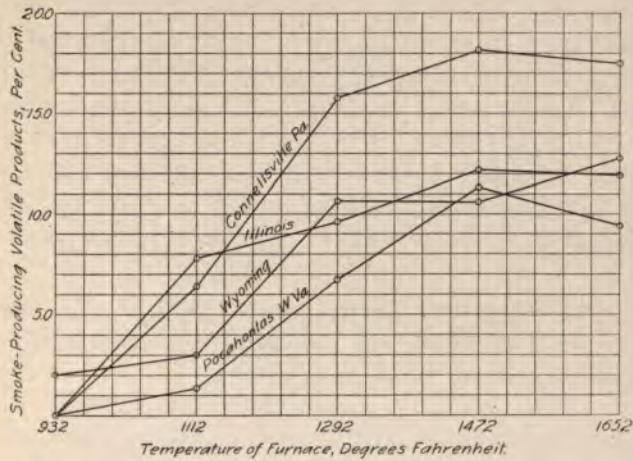
Fig. 8.

Proportion of Smoke-Producing Compounds of Coals.

a coal to produce smoke depends on both the relative total quantity of the volatile matter and on the relative ease with which the smoke-producing volatile matter is given off. Coals differ considerably in the latter respect, as is shown in the diagram, Fig. 8. The curves are plotted from data of a test conducted by the Bureau of Mines in heating 10 grams of air-

dried coal 10 minutes; the data being taken for the temperatures given. The curves show the total smoke-producing products, consisting of tarry matter and heavy hydrocarbons in the form of C_2H_6, C_2H_4, C_6H_6, etc. The distillation of smoke-producing products from the Connellsville coal begins at about 900° F., and progresses at practically an even rate up to about 1,300° F., when practically all the heavy hydrocarbons are driven off. The Illinois coal gives off practically two-thirds of its smoke-producing matter between 900° and 1,100° F., the smoke-producing matter distilling quite gradually before 1,100° F. The rapid production of large volumes of smoke-producing volatile at low temperatures makes both of these coals difficult to burn without objectionable smoke unless special provisions for the prevention of smoke are made. However, the smaller total volume of heavy hydrocarbons produced by the Illinois coal makes that the easier coal of the two to burn smokelessly.

The Wyoming coal is the next best smoke producer, as it gives off practically all its heavy hydrocarbons between 1,100° and 1,300° F. The Pocahontas coal contains about the same amount of smoke-producing matter as the Wyoming coal, but it distils its volatile more gradually and at a higher temperature, distilling between 1,100° and 1,500° F.

The maximum quantity of heavy hydrocarbons is about the same for the Wyoming and the West Virginia coals. However, the time required for their distillation varies considerably. The Wyoming coal distils its gas in two-thirds the time required by the Pocohontas, while an equal volume of gas from the Connellsville coal is distilled in one-half the time. The difference in the time element of distillation in

different coals is quite a factor in the production of smoke, the shorter the time element, the more difficult it is to prevent smoke.

Prevention of Smoke from Tarry Vapors.—From the foregoing discussion it will be seen that to burn smokelessly coals that are rich in heavy hydrocarbon gases and in tarry vapors; the coal must be heated slowly, so as to reduce to a minimum the amount of tarry vapors and higher hydrocarbons that are driven off; the temperature of the combustion space must be high enough to furnish sufficient heat quickly to gasify the vapors promptly as they are produced; an adequate supply of air to burn completely the gas thus produced must be admitted into the combustion chamber; the air supply must be intimately mixed with the gases; and the time of flight of the volatile to the tubes must be sufficient, so that the volatile will be completely burned before coming in contact with the cold surfaces of the boiler.

Honeycomb.—In locomotive service, coal rich in tarry vapors frequently has to be burned in fireboxes that are not properly designed to burn that type of coal. The result is that clouds of dense, black smoke are formed by the tarry vapors, and honeycomb, or flue sheet clinker, sometimes forms on the tube sheet, covering the ends of the tubes and stopping the flow of hot gases through such tubes. The honeycomb will continue to grow and spread, and eventually it will cover the tube sheet, if they are not knocked off periodically by means of a long iron rod introduced through the firedoor. The honeycomb in this case is formed by the tarry matter that strikes against, and is condensed on, the tube sheet. The tar is "coked" on the sheet by the heat of the firebox, and collects

particles of ash and fine coal that are carried bodily through the furnace by the gases of combustion. This results in the formation of a hard substance that grows or spreads over the face of the tube sheets in a comparatively short time. The formation of honeycomb is aggravated by flue leakage as the leakage tends to reduce the firebox temperature, which in turn retards the vaporization of the tarry globules. Fine particles of a caking coal may cause honeycomb to form also, owing to the particles striking the tube sheet while in a pasty condition and adhering and caking on the sheet.

Heat Losses Due to Smoke.—The production of smoke is objectionable both from the standpoint of the public and of the power-plant owner. The public is interested because of the heavy, yearly financial loss through the deterioration of property, etc. caused by soot from smoking chimneys; also, because of the detrimental effect on the health of a community and on the vegetation in the vicinity of smoky stacks, due to the soot and to harmful, but invisible, waste gases that escape from the smoke. These waste gases consist of the poisonous carbon monoxide, of unaltered hydrocarbons and tarry vapors, and often of sulphur vapors. The plant owner is directly interested in smoke abatement because of the financial loss sustained through the waste of the fuel gases that escape unburned with the smoke.

Black smoke is a sure indication that, for some reason, the combustion is incomplete, consequently, that a direct fuel loss is occurring, and the blacker the smoke, the greater is the fuel loss through the escape of unburned gases. On the other hand, the absence of smoke does not always mean complete

combustion or the elimination of waste of unburned gases, as the stack may be cleared up through excessive air dilution. This method of smoke suppression is very wasteful, since, at times, it produces a loss of furnace temperature, Table XXVI, that causes a great waste of heat through gases that escape unburned. The best economy will be obtained with the air supply cut down until the stack gives off a light smoke the color of gray mist, as this insures against excessive air dilution.

Smoke may indicate a loss of heat through unburned carbon as soot, through unburned gases that escape as carbon monoxide and as unaltered hydrocarbons, and through tarry vapors. The loss through the soot in smoke is very small, seldom exceeding 1 per cent. of the fuel burned. Soot is so light that it requires but a small amount or weight to give the smoke a dense, black color. If, therefore, the soot were the only waste that occurred through smoking, the saving through soot prevention would not warrant much expense to effect it. However, soot is a danger signal that signifies incomplete combustion, the losses through which may be many times the loss due to the soot.

For each pound of carbon monoxide that escapes in the smoke, 10,250 B. T. U. are lost, and this loss, in some cases, may amount to .5 of 1 per cent. of the total heat of the coal. While the amount of CO loss increases usually with the density of the smoke, yet, the density may not indicate the proportion of loss due to CO. With a perfectly clean chimney, the CO loss is very small, not exceeding .05 of 1 per cent. of the total heat of the coal.

In the the greater number of instances where chimneys smoke badly and the coal is rich in heavy

hydrocarbons and in tarry vapors, the loss through unburned volatile combustible gases and tarry vapors may amount to 3 to 10 per cent. of the total heat value of the fuel.

The number of heat units lost per pound of the different hydrocarbons can be seen from Table XVII. For coals rich in tarry vapors, the vapor loss probably forms the greater part of the heat loss due to incomplete combustion.

CHAPTER XVII

BURNING COAL SMOKELESSLY

IN the discussion on the smokeless combustion of fuel, it was seen that four factors enter into smokeless combustion; namely, the air supply, the intimate mixture of the volatile matter and the air, the temperature in the combustion chamber of the furnace, and the interval of time allowed the volatile matter in which to burn while in the combustion space.

Fixed Carbon.—In burning, carbon is found in three forms that are of interest; namely, as fixed carbon, as gaseous or free carbon, and as soot. The fixed carbon is that part of the coal, called coke, that remains after the gases of the coal have been driven off. Fixed carbon combines with oxygen and burns when at a red heat, and it remains incandescent as long as combustion goes on, the heat produced in burning being sufficient to maintain incandescence. It burns without flame, the coke merely glowing. Coke cannot produce smoke in burning, because its carbon cannot be liberated as free carbon to form soot. It can exist as carbon only in the coke. In burning, it forms invisible gas, CO_2. Under certain conditions in a restricted supply of air, it may pass off with only 1 atom of oxygen, as CO, but that gas is invisible also.

The problem of smokeless combustion, therefore, consists in burning the free carbon of the volatile matter of the coal. The gases given off by coal

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can be burned smokelessly, just as illuminating gas is, if conditions for properly burning them are favorable. On the other hand, anything that tends to affect the conditions for smokeless combustion unfavorably will tend to cause smoke.

Air Supply.—The proper supply of air to the fire is one of the really important matters connected with economical firing. Approximately 250 cubic feet of air is needed to furnish oxygen for the complete burning of 1 pound of bituminous coal. For each scoop of 15 pounds, it will require $15 \times 250 = 3,750$ cubic feet of air, and, if five scoops are fired at a time $5 \times 15 \times 250 = 18,750$ cubic feet of air must be supplied for each fire put in. With a hand-fired furnace having a grate area of 67 square feet, and burning 20 pounds of coal per square foot of grate surface per hour, $67 \times 20 \times 250 = 335,000$ cubic feet of air per hour, or 5,584 cubic feet per minute must be supplied. This requires a good draft, a good, clean fire, and an ample ashpit opening through which the air can enter the furnace freely. Furthermore, provision must be made for a free admission of air into the furnace room.

Distillation of Gases.—If the gases were distilled from the coal at a uniform rate, their burning would be very much simplified, because the air supply could then be accurately regulated to give the proper mixture of air and gas for complete combustion. Unfortunately, in hand-fired furnaces, the distillation of the volatile is very irregular. The firing is done at more or less irregular intervals, and after each fire is put in a large volume of gas is distilled within a space of a few minutes while the coal is being heated to the furnace temperature. To burn

completely, the gases require a larger supply of air than should be supplied to the fixed carbon after all the gases have been distilled. If, therefore, the air supply is adjusted to take care of the gases, then it will be too great for the fixed carbon after the gases are distilled, and will cause a loss of heat through excess air, Table XXVI. If the supply is adjusted for the fixed carbon, then it will be insufficient to burn all the gases, so that a loss through unburned gases will result. It is evident, therefore, that to obtain the best results either the coal must be fired at a uniform rate, so that the gases will be distilled uniformly and continuously, or the air supply must be adjusted to the proper amount for the fixed carbon and then be increased sufficiently to take care of the gases during the time the gases are being distilled. The method of uniformly distilling the gases is made use of in the mechanical stoker, and, approximately, in hand-firing when the coking method of firing is employed. The method of adjusting the air supply to the condition of combustion is used in hand-firing when either automatic or non-automatic air admission above the fire is made use of.

Admission of Air. — For furnaces equipped for hand-firing in which the distillation of the gases is not uniform, the air required for firing the fixed carbon of the coal can be supplied through the grates, but the air for burning the distilled gases and for assisting in the combustion of the upper layers of coal when the fire is very thick must be supplied from above the fire.

The air supplied above the fire should be admitted in small streams, so that the air will be heated as quickly as possible and will be more thoroughly mixed with the gases. The greatest volume of air

for the gases should be supplied when the coal is first fired, and the supply should be diminished as the quantity of gases distilled diminishes.

Results of tests show conclusively that the weight of the air used to burn 1 pound of combustible decreases as the rate of combustion increases, and this indicates that the rate of combustion more than keeps up with the velocity of the current of air through the fuel bed. In other words, the higher the velocity of the air through the burning fuel, the higher will be the rate of combustion. As an example, during a test a certain plant using forced draft required 22.5 pounds of air per pound of combustible when burning 20 pounds of coal per square foot of grate surface, and only 20 pounds of air when burning 70 pounds of coal.

The air supply above the fire should be regulated to suit the combustion of different kinds of coal, and it should be supplied automatically, so as to overcome the personal element that enters into hand regulation. When no special means for air admission above the fire are provided, conditions may be helped somewhat by cracking the furnace door for a couple of minutes after each fire and then closing it when the gases are nearly all distilled.

The firedoor should not be opened wide for the admission of air, because the large volume of cool air thus allowed to pass through the furnace in a solid stream would not mix with the gases, but would absorb and carry away so much heat that the loss through excess air would far exceed any possible gain through the admission of the air. It is common, but poor, practice with some firemen to open the firedoor when there is a liability of the safety valve opening, so as to cool the furnace and prevent

the safety valve from popping. The same detrimental effect is noticed if holes are allowed to form in the fire.

Effect of Clinker Holes and Thick Spots.—Clinkers, large lumps of coal, and thick spots and thin spots in the fire, all tend to disarrange the proper admission of air through the grates. The draft draws the most air through the spots offering the least resistance—the thin spots—and this tends to burn a hole quickly in the fire at such points. The thick spots, on account of their greater resistance, have less air passing through them, so that the combustion is very slow and thus the tendency is for the spots to become thicker and thicker and, with poor coal, to form a clinker. A clinker acts as a "dead plate," because no air can pass through it. Its tendency is to form a dead spot in the fire. Large lumps of coal fired unbroken with the fine coal of run-of-mine coal cut down the active grate area to the extent of the area of the lump. Also, the fine coal burns much faster around the edges of the lump, thus tending to burn a hole through the fire around the lump. The effect of dead spots and of light spots is to make the admission of air uneven throughout the surface of the fire, thus causing different rates of combustion at different parts of the fire and resulting in the production of smoke and waste of unburned gases.

Draft.—It is impossible to burn bituminous coal smokelessly unless there is an ample draft capacity available. Poor draft is a most aggravating source of trouble and loss. Because a chimney is high it does not follow that the chimney will produce sufficient draft under all conditions. The cross-sectional area may be too small, thereby causing too great a drop of pressure in overcoming the resistance of the

stack; thus there will not be sufficient draft for the proper acceleration of the gases. The chimney may be high enough to produce the draft and of large enough area, yet the draft may be used up in overcoming the resistance of a number of elbows in the smoke flues leading from the boiler to the stack, or there may be sufficient leakage in the boiler setting, smoke flues, and breeching to use up a good portion of the draft. Also, weather changes have considerable effect on the draft produced by a chimney. This is very noticeable where all the available draft is required to carry the load of the plant.

To obtain the best service, a chimney should be so proportioned as to have draft in reserve above that required for the full load of the plant, the draft being regulated by means of the draft control arrangement in the breeching. This is a better method of regulating the draft than by means of the ashpit doors, since the latter method favors the escape of the volatile gases unburned through the direct action of the draft.

Where two or more furnaces are connected to the same chimney, the draft of each furnace should be regulated separately. If this is not done, the furnace nearest the chimney will be working above its rating and thus may smoke badly, whereas the furnace furthest away may be working at or below its rating and without smoke. This will be indicated by smoke appearing at the stack, whereas, by equalizing the rates of combustion in the two furnaces, the smoke may be prevented.

Mechanical or artificial draft does not burn coal any more efficiently than natural draft, but it can supply ample air for high rates of combustion or for the burning of inferior grades of coal, and it is inde-

pendent of weather conditions. Also, it places the engineer in absolute control of the draft, so that he can quickly and accurately adjust the draft to sudden changes of load. Natural draft is practically constant, and its control rests principally on the operation of the dampers, which restrict the flow of air, but do not affect the intensity of the draft produced by the chimney. With mechanical draft, the dampers are usually left wide open and the intensity of the draft is regulated by changing the speed of the fan. For variable conditions of service, the throttle of the fan is operated by an automatic draft regulator so constructed that the throttle is opened wider and the fan speeded up when the steam pressure falls, and vice versa, thus obtaining close regulation of the steam pressure.

Draft has two functions to perform. It must overcome the resistance of the grates, fire, combustion chamber, tubes, breeching, uptake, etc., and must be sufficient to impart the necessary velocity to the requisite amount of air for complete combustion at maximum rates of steam production.

Under average conditions, about 75 per cent. of the total draft is expended in overcoming the resistance of the grates, about 19 per cent. in overcoming the frictional resistance of the flues and chimneys, and only about 6 per cent. in accelerating the gases. Since the rate of combustion in the furnace and the rate of absorption of heat by the boiler are directly proportional, respectively, to the velocity of the air through the fire and to the velocity of the gases of combustion through the tubes, it is very important that the chimney have sufficient height to provide ample draft for the acceleration of the gases under all conditions of operation. Table XXX gives the

draft, in inches of water, produced by chimneys of different heights at sea level. These values must be corrected for elevations above sea level. The height is the distance that the stack extends above the grates.

TABLE XXX.
Relation of Height of Stack to Draft.

Height, Feet	Total Draft, Inches of Water	Height, Feet	Total Draft, Inches of Water
50	.364	130	.948
60	.437	140	1.029
70	.512	150	1.095
80	.583	180	1.313
90	.675	200	1.459
100	.729	225	1.641
110	.802	250	1.825
120	.875	300	2.189

The area of the chimney must be such that the average velocity of the gases in the chimney, in feet per second, multiplied by the area, in square feet, will be slightly greater than the volume of air necessary for combustion at the maximum rate at which the coal is to be burned.

Steam Jets for Mixing the Air and Gases.—In burning high-volatile, smoky coals, an intimate mixture of the air supply above the fire and the volatile matter, while in the combustion chamber and at the proper temperature, is absolutely essential, in order to avoid the production of smoke and the waste of heat through unburned gases. With hand-fired furnaces, especially, the combustion space, to be most efficient, must have some means of mixing the air and the gases.

When coal of moderate smoking qualities is used, mechanical draft has sufficient power to furnish an adequate supply of air through the grates and fire for complete combustion. Thus admitted, the air is broken up into numerous fine streams that mix thoroughly with the gases as they are distilled. For rich, smoky, volatile coals, mechanical draft can furnish a portion of the air above the fire (preheated if necessary) in the form of jets so directed as to mix intimately with the gases as they rise from the bed of the fire.

With natural draft, a series of steam jets operated on the principle of the ejector have been employed to induce a flow of air into the furnace above the fire. The jets of steam and air are hand controlled and are directed downwards, so as to produce a thorough mixing of the air and the gases.

The second method consists of automatic steam-and-air admission devices that are thrown into operation on opening the firedoors and remain in operation after the doors are closed for an interval depending on the adjustment of a dashpot that regulates the length of time that the steam jets are in operation. The air above the fire is admitted through an air-admission door in the firedoors. The steam jet is directly above the center of the firedoor and is directed downwards, so as to intermingle the incoming air and the gases arising from the burning coal thoroughly.

While these methods are quite successful in preventing smoke, yet they are objectionable on account of the noise they make while operating, as well as the high cost of operation, due to the large steam consumption.

The steam jets, by introducing steam and air

above the fire, cut down the amount of air that passes through the grates and the bed of fire while the jets are in operation. The steam itself is objectionable, because it will not burn, it excludes its own volume of air, and it is superheated and carries the heat out of the stack and thus wastes this heat. On the other hand, the mixing action of the jets brings the air that is introduced above the fire into more intimate contact with the gases, thereby insuring better combustion and air economy and less smoke. This, in a measure, offsets the direct loss due to the use of the steam. The results of using steam jets, therefore, are a quicker and better combustion of the gases, and a slower combustion of the fixed carbon during the time that the steam jets are in operation.

In the endeavor to avoid the losses resulting from the use of steam jets, different arrangements of firebrick arches and piers have been employed to mix the air and the gases. However, the difficulty has been to build arches and piers that will withstand the intense heat emanating from the combustion of the intimately mixed gases. Also, the piers and arches increase the resistance to the flow of gases to the stack and thus reduce the available draft, besides reducing the capacity of the combustion space. If these factors are not reckoned with in the design of a plant, a reduction in the capacity of the furnace to burn coal will result.

Automatic Air-Admission and Steam-Jet Mixing Devices.—The object of the automatic air-admission device is to make the admission of air above the fire, after fuel has been added, independent of the fireman. Fig. 9 illustrates one of these devices applied to a furnace under a water-tube boiler. *1* is the dashpot closed after the firedoor has been closed; *2* is the
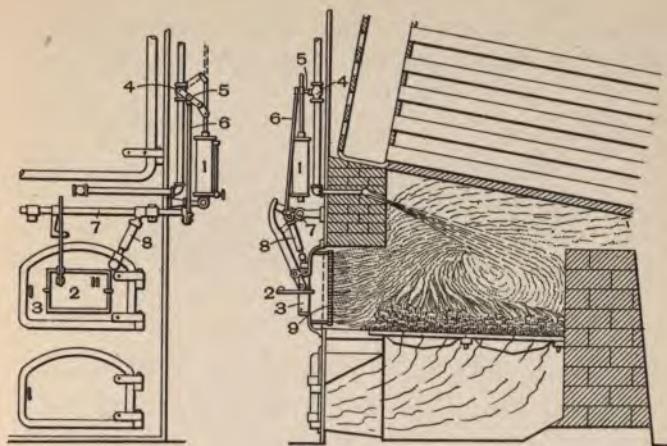
Fig. 9.
Automatic Air-Admission Device.

air admission through the furnace door *3*, the air being split up into fine streams by the perforated plate *9*; *4* is a cock that controls the supply of steam to the steam jets. The handle *5* of the cock is connected both to the spindle of the dashpot *1* and to the link *6*, which is connected to, and operated by, the shaft *7*. The shaft is operated by the arm *8*, which is connected to the furnace door *3*. Opening the door *3* turns the shaft *7*, which operates the link *6* and raises the handle *5* of the cock *4* to "open" position, indicated by the dotted lines. This opens the cock *4* and turns on the steam; also, it raises the dashpot plunger. After the firedoor has been closed, the steam jets continue to operate for a short interval, depending on the adjustment of the dashpot *1*, after which they are automatically shut off. In this arrangement, the jet of steam is employed solely to mix the air and the gases.

Fig. 10 shows the piping arrangement for dis-

tributing steam to the jets. The piping is located within the furnace walls, in order to protect it from the direct heat of the fire.

Fig. 11 shows a vertical section through a re-
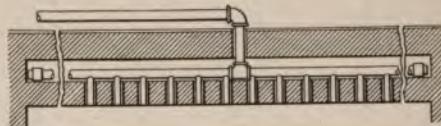
Fig. 10.
Arrangement of Steam Jets.

turn-tubular boiler with a similar automatic steam-and-air admission device. With this arrangement, the air for above the fire is admitted to the furnace through the ashpit air admission 2, which is opened by the firedoor and is regulated by the dashpot.
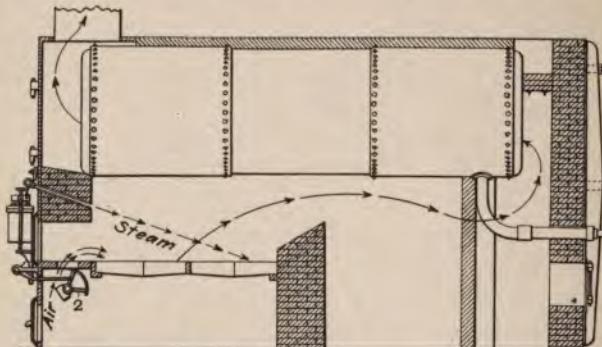
Fig. 11.
Automatic Steam and Air Admission Device.

Non-Automatic Air Admission.—A method of air admission for use with tubular boilers, which was experimented with by Messrs. Flagg, Cook, and Woodman, of the Bureau of Mines, Technical Paper 34, is shown in Fig. 12. In these tests, two methods of supplementary air supply were tried out. One,

admitted the air at the front end of the furnace; the other admitted it through the rear face of the bridge wall, as shown.

For the front-end air admission were used, eight rectangular openings having a total area of 115 square inches, or about 5 square inches per square foot of grate area. The air openings were equally spaced across the front wall of the furnace, and opened into an air passage about 8 inches by 10 inches. The passage was divided in the middle, so as to separate the air admission openings into two separately controlled groups, one for each half of the furnace. Each of the air passages was provided with a sliding door in the boiler front, for control of the admission of the air to the passage.
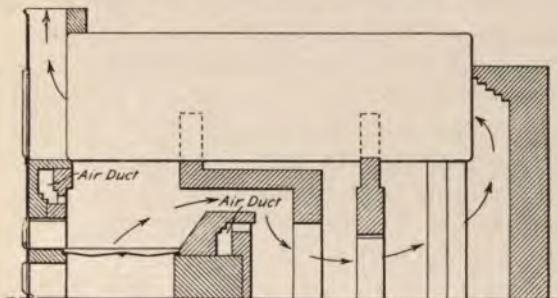
Fig. 12.
Cross Section of Furnace Showing Air Ducts.
Non-Automatic Air Admission.

The bridge-wall arrangement consisted of an air-passage about 8 inches by 10 inches, controlled by means of a sliding door similar to that used for the front-end passage. There were eighteen air openings into the combustion chamber, with an area of 67 square inches, or about 3 square inches per square foot of grate area. The sliding doors permitted the fireman to graduate the air admission

from no air, with the doors closed, to full air admission.

The front-end admission gave best results during the tests, due to its admitting air in front of the fire, and, therefore, to the better chance of the air being thoroughly mixed with the gases while in the combustion chamber. Under most conditions, therefore, front-end admission alone would be sufficient. However, with a very smoky coal, auxiliary air admission at the bridge, with suitable mixing facilities, would very probably burn smokelessly coal that could not be so burned with the front-end admission alone.

Capacity of Combustion Chamber.—A furnace well designed for smokeless combustion and properly operated will burn many kinds of coal smokelessly up to a certain number of pounds of coal per square foot of grate area per hour. The maximum rate for the different coals will vary considerably, depending on the percentage and the richness of the volatile matter of the coals, on the draft, and on the manner in which the firing is performed. If the maximum rate for any coal is exceeded, smoke will result, owing to the lack of capacity of the combustion chamber to supply sufficient air and properly mix it with the gases before they reach the tubes. This may be stated in another way, as follows: The combustion chamber of a furnace is smokeless for any given coal up to a given rate of combustion; this rate is different for different coals, but should an attempt be made to burn a coal faster than at its limiting rate smoke will result. Therefore, in burning coals in which the per cent. of volatile gas and tarry vapors is high, the size of the combustion chamber of the furnace is very important, both from the standpoint of efficiency and from that of smokeless combustion.

The size of this chamber depends on the maximum volume of volatile combustible to be burned per second and on the richness of the volatile in heavy hydrocarbons and in tarry vapors. The higher the percentage of volatile combustible, the larger the combustion space must be in order to provide sufficient space for the air for combustion, for proper intermingling of the air and gases, and for time in which the gases can completely burn before coming in contact with the cold surface of the boiler. The gases are in the combustion space for only a fraction of a second. Record of tests of marine, locomotive, and stationary boilers show that for the boilers under test, the time, in seconds, that a cubic foot of gas was in the combustion space varied from .07 to .08 second for marine, from .16 to .19 second for locomotive, and from .45 to .65 second for natural-draft stationary practice, the time interval depending on the construction of the furnace in each case.

For equal volumes of volatile to be burned, a slow-burning volatile rich in heavy hydrocarbons and in tarry matter will require much more combustion space than will a quick-burning volatile of lighter hydrocarbons. Increasing the size of the combustion chamber by increasing either its length or its area lengthens the time that the volatile is in the chamber. Lengthening the chamber lengthens the path of the gas, while keeping the length constant and increasing the area decreases the velocity of the gas through the chamber. Provision for the thorough intermingling of the air and the gases permits of a smaller combustion chamber than otherwise; hence, a combustion chamber in a furnace that is too small may often be assisted by the use of some system for intimately mixing the air and the gases.

Since the size of the combustion chamber depends on the maximum rate of burning the gases, anything that will increase that rate will require an increase in the size of the combustion chamber or, with a combustion chamber of given size, will decrease the rate of combustion at which the furnace will smoke. The rate of distillation of gases is proportional to the rate of the rise of temperature of the coal. Therefore, since fine pieces of coal will heat more rapidly than large pieces, it follows that to burn fine coal smokelessly in a hand-fired furnace will require a larger combustion space than to burn large coal smokelessly at the same rate of combustion. On the other hand, with mechanical stokers, small sizes of coal can be burned with less smoke than large sizes, but, they will develop lower boiler capacity.

If a coal is fired in a continuous stream at a uniform rate, as when mechanical stokers are used, it will make the rate of distillation of the volatile matter uniform and will greatly reduce the maximum rate of distillation.

In hand-firing, if large quantities of coal are thrown on the fire at long intervals, the maximum rate of gas distillation will be greatly increased, whereas, if small amounts of coal are fired at frequent intervals, the maximum rate will be reduced considerably. It will thus be seen that the method of firing has much influence over the limits of smokelessness of a furnace. A certain furnace, hand-fired, was smokeless up to a rate of combustion of 24 pounds of coal per square foot of grate surface per hour; the same plant fitted with a chain-grate stoker increased the smokeless capacity of the furnace to 42 pounds per square foot of grate surface per hour.

When a fire is burning brightly and smokelessly, gradually close the dampers so as to cut down the draft, and a point will be reached, depending on the rate of combustion, where smoke will be produced. Open the dampers a little so as to increase the draft and thus increase the rate of burning coal, and a second point will be reached where smoke will be produced. Again open the damper a little so as to increase the draft still more and the smoke will again clear up. Increase the rate of burning and smoke will again appear, but it will be cleared up on opening the damper farther and increasing the draft. These experiments show that a furnace has a definite smokeless capacity for a definite value of the draft, and that increasing or decreasing the draft increases or decreases the smokeless capacity of the combustion chamber.

Increasing the thickness of a fire reduces its smokeless capacity in two ways—by decreasing the effective draft and by decreasing the volume of the combustion space. Increasing the thickness from 8 to 14 inches on a 48-square-foot grate would reduce the volume of the combustion chamber $48 \times \frac{6}{12} = 24$ cubic feet. If the volume of the combustion chamber with an 8-inch fire were 200 cubic feet, increasing the thickness of the fire to 14 inches would reduce the volume of the combustion chamber 12 per cent. The range of smokelessness would be affected by this reduction and by the decrease in the draft due to the increased thickness of the fire. Also, the thicker fire would produce greater quantities of CO, thus increasing the volume of combustion space required.

From the foregoing discussion it will be seen

that if a furnace smokes habitually, the capacity of the combustion chamber has been exceeded for the conditions of the draft, for the kind and size of coal, the method of mixing the air and the gases, or the method of firing the coal. If the limit of the draft is exceeded, the rate of combustion will have to be cut down or the draft will have to be increased, by mechanical means or otherwise, until the smoking ceases. Adjusting the air admission above the fire and properly mixing the air and the gases may clear up the trouble. If these methods are impracticable, a change in the grade or in the size of the coal used may answer. Carrying a lighter fire and firing in small amounts will frequently assist very materially in reducing the smoke, unless, of course, the fire carried is already too thin.

If a plant has been operating smokelessly and then begins to smoke habitually, it is possible that some of the baffles in the boiler have been burned out, so that the gases and the flame take a short-cut that allows the flame to strike the tubes or cool boiler sheets and thus cause the smoke.

Furnace Temperature, and Power Developed.— The temperatures in the furnace should at all times be uniform and high enough to volatilize the tars and dissociate the gases and to ignite the gases as they are distilled from the fuels. On the other hand, extremely high temperatures should be avoided, because they are due to an air supply that approaches the theoretical amount too closely, thereby resulting in smoke and in loss of heat through unburned gases, due to restricted air supply.

In order to insure a more uniform temperature in a furnace, the combustion chamber is made of fire-brick and of sufficient size to mix the air and the

gases thoroughly and insure their complete combustion. The temperature of the furnace rises with the rate of combustion, that is, with each increase in the power that is being developed by the boiler. With natural draft, hand-fired furnaces burning up to 25 pounds of coal per square foot of grate surface per hour, the temperature may vary from 1,600° F. under adverse conditions at low boiler capacity to 2,200° F. at or above full boiler capacity. With mechanical stokers, the temperature may vary from 1,800 to 2,600° F. With forced draft and mechanical stokers burning up to 80 pounds of coal per square foot of grate surface per hour, the temperature may vary from 1,800° to 3,100° F. The furnace temperature for a given rate of combustion is higher and much steadier when a mechanical stoker is used than when the furnace is hand-fired.

Temperature and Thickness of Fire.—In order to maintain a uniform temperature in a furnace, the fuel on the grates must be of the proper thickness, loose and penetrable, and without holes or very thin spots. The proper thickness depends on the draft, the kind of coal, and the rate of operation of the boiler. If the fire is too thin, it will admit too much air, which will cool the furnace temperature greatly and will carry away considerable heat, which is a direct loss. Also, the cooling effect of the coal fired is greater with a thin fire than with a thicker fire; therefore, the fluctuations in furnace temperature will be greater.

If the fire is too thick, or dirty, it causes troublesome clinkers and the heavier draft required increases air leakage through the boiler settings, thereby lowering the smokeless range, the efficiency, and the capacity of the furnace.

A lighter fire will have to be carried with a poor draft than with a good draft. On the other hand, the stronger the draft, the thicker the fire must be for best economy. A much thicker fire must be carried with forced draft than with natural draft. Where a 7-inch or 8-inch fire would be carried with natural draft and allowed to burn down to 3 inches, a 10-inch fire would be carried with forced draft, and it would not be allowed to burn down below 7 inches. Also, for each load carried by the boiler there will be a definite thickness of fire that will give the best efficiency, the thickness of the fire being greatest for full load and decreasing with each decrease in the load. As an example, during a boiler test with a certain boiler plant and grade of coal, the maximum efficiency for $1\frac{1}{4}$ load occurred with an 8-inch fire; for full load, with a 7-inch fire; for $\frac{3}{4}$ load, with a 6-inch fire; and for $\frac{1}{2}$ load, with about a 5-inch fire, 5 inches being the least depth of fire that could be carried efficiently with the coal burned.

Weathered coal requires more draft and a thinner fire than fresh coal. Sized coals and coals that lie loosely on the greate may be carried thicker than coals that, by reason of their size and shape, pack closely. The smaller the coal, the thinner the fire may be, but it should not be so thin that the draft will raise the pieces and allow the air to break through. Buckwheat coal may be carried from 2 inches to 5 inches, depending on the draft. Data of sixty-four Government efficiency tests with natural draft and with the same plant burning slack, run-of-mine, pea, nut, and lump coal from sixteen states show the best thickness of fire carried for the different tests to vary from 4 inches to 14 inches, with an average of 8.4 inches, as in Table XXXI.

TABLE XXXI.

Thickness of Fire Carried in Sixty-four Tests.

Kind of Coal	No. of Tests	Thickness of Fire, Inches									
		4	5	6	7	8	9	10	11	12	14
Slack	1	..	..	1	..	..	..	..	..	..	..
Run-of-mine .	13	..	..	2	..	5	1	4	..	1	..
Pea	1	..	..	..	..	1	..	..	..	..	..
Nut	45	1	1	3	9	14	4	4	3	5	1
Lump	4	..	1	..	..	1	1	1	..	..	..
Total	64	1	2	6	9	21	6	9	3	6	1

The amount of slack in the coal varied considerably. The pea coal was 50 per cent. of fine coal and 50 per cent. of slack. The nut varied from 20 per cent. of nut and 80 per cent. of slack to 80 per cent. of fine and 20 per cent. of slack. The run-of-mine varied from 10 per cent. of lump, 45 per cent. of fine, and 45 per cent. of slack to 80 per cent. of lump, 10 per cent. of fine, and 10 per cent. of slack.

For a given thickness of fire, the furnace temperature will vary, depending on the quantity of coal fired at a charge. Both the coal fired and the stream of cold air admitted through the furnace door absorb heat and reduce the furnace temperature; therefore, the least variations will occur when the coal is fired in small amounts and frequently, the furnace door being swung shut after every scoopful or else being held open a small amount for a short interval after each fire.

Time Factor in Furnace Combustion.—Time has a very important influence on the smokeless and efficient combustion of the gases of a coal, because the gases begin their flight from the combustion chamber the moment they are distilled. They have but a fraction of a second in which to mix intimately

with the air and burn while in the combustion chamber and before they come in contact with the tubes and cold parts of the boiler. If they do not have sufficient time in which to burn, they pass off unconsumed, because they are cooled below their igniting temperature.

Significance of Length, Color and Motion of Flame.—Where provision is made for observation of the appearance of the flame, a knowledge of the length and the color of the flame will assist very materially in the prevention of smoke. The end of the flame indicates the point where the combustion of the gases ends, as it is the burning gases that produce the flame.

If the flame is white and quite short and waves violently, like a flag in the wind, and the stack does not smoke, the indications are that the fire is too thin and allows too much air to pass through it. With proper admission of air, the flame will be bright yellow or reddish, and will roll and wave, and, at full capacity, will fill the entire combustion chamber, and the chimney will omit a light-gray smoke. If the flame is long, dark, and smoky looking, and the stack smokes badly, it indicates a restricted supply of air, a poor mixing of air and gases, or a low furnace temperature. Where the flame is dark-yellowish or reddish, indicating a fairly good air supply, but is so long that it reaches the tubes and cool surfaces of the boiler, and the chimney smokes badly, it indicates that the capacity of the combustion chamber has been exceeded. The smokeless capacity of the furnace is just reached when the length of the flame is such as to be just short of reaching the tubes and cool surfaces of the boiler. With a proper air supply, the length of the flame is proportional to the

quantity of gases to be burned and to the proportion of hydrocarbons and tarry vapors. The length and the color of the flame for any coal, therefore, indicate when the smokeless capacity of the furnace has been reached for that coal.

Smokeless Capacity of Furnace.—Every type of furnace has a maximum rate of combustion for a given kind of coal, which, if exceeded, will result in the production of smoke. This rate is dependent on the type of the furnace, the capacity of the combustion chamber, the method of baffling the boiler, and the methods used for mingling the air and the gases. Furnaces built with the idea of smoke prevention usually are designed so that, with hand-firing and the proper coal, with average care in firing, and without using all the available draft, the maximum smokeless capacity will be attained at from 80 to 100 per cent. of the rated capacity of the boiler. Under like conditions, except with natural draft and with mechanical stokers, the smokeless capacity will be attained at from 100 to 140 per cent. of the rated capacity of the boiler.

Usually, a furnace that will give smokeless combustion at or above full boiler capacity will not give smokeless combustion much below 50 per cent. of the boiler capacity, as the furnace will be too large for light loads. Also, a furnace that will give smokeless combustion for light loads will smoke at or near full loads. Therefore, the size of the furnace must be chosen with a view of the range of smokelessness desired.

The smokeless capacity of a furnace for a given coal can be increased by lengthening the time interval of the gases in passing through the combustion space. This may be accomplished by keeping the

area constant and lengthening the combustion chamber; by lengthening the path of the gases through the use of baffles or arches; by decreasing the velocity of the gases through the combustion chamber through increasing the volume of the chamber without increasing the length; or, by increasing both the length and the volume of the combustion chamber.

If a plant is burning a rich, tarry coal and smokes badly, the smoke can often be reduced to an unobjectionable amount by using a coal low in tarry matter, by using a sized coal, or by changing the size of the coal and the method of firing. When a coal is rich in tars and heavy hydrocarbons, heating the coal slowly during the distillation period will tend to avoid the distillation of the heavy hydrocarbons and thus reduce the amount of smoke formed. Coals that smoke badly give from 3 to 5 per cent. less efficiency than coals that smoke but little.

Influence of Size of Coal.—Data from numerous tests show that small sizes of coal burn with less smoke than large sizes, but that the larger coals burn more readily and produce higher boiler capacities. Also, the large coals use less air per pound of combustible, but they cause considerable black smoke at the higher capacities.

To develop high boiler capacities, the coal burned should be sized, with the slack and the dust removed. Coals of different sizes containing slack and dust have a tendency to pack on the grate, owing to the way in which the pieces arrange themselves. Also, such coals contain a higher percentage of ash. This results in less air being forced through the fire for a given draft value, hence in a lower combustion rate and in reduced boiler capacity.

Results of tests made on twenty-six different

coals from eleven states and on the same coals washed indicated that most of the washed coals burn freely (non-coking) and seem to burn more rapidly than the unwashed coals; also, they develop a greater percentage of the rated boiler capacity. The washed coals burn with lower efficiency and make more smoke than the unwashed coals, the lower efficiency being due to burning the coal wet. The average per cent. of moisture for washed coal was about .58 per cent., although in some instances, washed coal contained as high as 5.5 per cent. more moisture than unwashed coal. The high water content of washed coal is offset somewhat by a lower ash-and-sulphur content. The ash in the dry coal varied from 5.39 to 23.16 per cent., and the sulphur from .58 to 4.78 per cent. The percentage of difference in the ash in the coals before and after washing varied from 1.23 to 10.07, with an average of 4.64 per cent. in favor of the washed coal; the sulphur difference varied from .02 to 3.64, with an average of .75 per cent. in favor of the washed coal. Lowering the sulphur content, lowers the tendency to clinker, so that washed coal produces a smaller percentage of clinker than unwashed coal. The water taken up by the coal in washing has to be evaporated in the furnace, and the heat thus absorbed and carried away reduces the temperature of the furnace and the capacity of the boiler. Average results of twenty-six compartive tests show an increased capacity for washed coals of about 6.5 per cent., with a decrease in efficiency of about 2.13 per cent.

Rocking vs. Flat Grates.—Results from twelve comparative tests of the same coals burned in the same furnace on rocking grates and on flat grates show an average of 2 per cent. greater efficiency with

the rocking grates than with the flat grates. In five of the tests, the rocking grates show an increased capacity over the flat grates; whereas, in the other seven tests, the flat grates show increased capacity. For the twelve tests, the flat grates show an increased capacity of 2.3 per cent. over the rocking grates. More coal is lost through the rocking grate than through the flat grate, and this reduces the efficiency of the rocking grate about 1.5 per cent.

The rocking grates gave better results in eleven out of the twelve tests, the one exception being a test of coal having 4.5 per cent. of sulphur, which fused with the ash and made bad clinkers. The clinker fused to the grate bars and rendered the rocking grate inoperative. In burning coals that are high in sulphur and that clinker, a flat grate will be more satisfactory than a rocking grate.

The smoke generated was slightly less with the rocking grate, as that grate afforded a better means of keeping the fire clean. In general, most coals that do not clinker badly can be burned on a rocking grate with from 1 to 5 per cent. greater efficiency and with a smaller percentage of black smoke than on a flat grate.

Conditions Unfavorable for Smokeless Combustion.—Any well-designed and properly proportioned furnace, provided it is fired intelligently with suitable coal of the right size and at the rates within the capacity of the furnace, may be expected to give smokeless combustion when the proper amount of air is supplied and intimately mixed with gases in the furnace. However, there are conditions of operation so unfavorable to smokeless combustion that even the best furnace will smoke.

In building a fire, the furnace and boiler are so

cold that the free carbon and the gases are cooled below their igniting temperatures and escape unburned, producing smoke. Also, with natural draft, the draft is so low when the fire is first started that the air supply is greatly restricted, and this further increases the tendency to smoke.

Banked fires are difficult to maintain and they waste the gases of the coal on account of the very restricted air supply through the fire and the very low furnace temperature. For similar reasons, in starting up a fire that has been banked, it will smoke badly.

If, where the load is variable, a large part of the power falls off quickly, the dampers and often the doors of the ash-pit are closed to check the draft and prevent a quick rise in the steam pressure. The amount of coal that was burning on the grate at the higher power is too large for the lower power being developed, so that the closed dampers restrict the air supply greatly and cause dense, black smoke.

With high-volatile coals, where the furnace is forced above its capacity, the volume of gas distilled is such that the length of the flame is longer than the combustion chamber and reaches the cool surfaces of the boiler, thus producing dense, black smoke.

Where the coal clinkers badly and the clinker adheres to the grate bars and closes the air spaces of the grates, the supply of air will become so restricted that dense, black smoke will result. Generally, coals that clinker the most, smoke the most.

If the baffling or the arch in the boiler is broken so as to allow the flame to take a short cut and thus strike the cold surfaces of the boiler, dense, black smoke will result.

CHAPTER XVIII

DRAFT REGULATION

RATE of Combustion, and Weight of Air Supplied.—It is well known that increasing the "draft" increases the rate of combustion. It is not so well known, however, that the increase in the rate of combustion is directly proportional to the velocity of the air through the burning fuel; that is, that there is a straight-line relation between the rate of combustion and the weight of air supplied through the fire per unit of time. Therefore, for best boiler efficiency and boiler economy, it is important that proper provision be made for the regulation of the draft.

Leaky Boiler Settings.—In a correctly designed power plant, the stack is so constructed as to give a draft in excess of that required for full-load furnace capacity, in order to insure sufficient coal-burning capacity under all conditions of operation. Where this draft is properly utilized, the full-load capacity of the boiler will be obtained. On the other hand, leakage through the boiler settings, etc. has an effect similar to a like reduction in stack-draft capacity on the full-load boiler capacity. The leakage not only increases the volume of stack gases to be handled, but also decreases the temperature of the gases in the stack, thereby reducing the draft. It is very important, therefore, that the brickwork, all doors, etc. be air tight, so that no air can enter the boiler or the furnace except through the grates or other places provided for that purpose.

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Tests for leakage can be made by means of a torch, leakage being indicated by the flame being drawn in at the point of leakage. Tests for leaks should be made of all cracks, the plates about the clean-out doors and blow-off pipes, around the arch over the combustion chamber at the rear, around the breeching, etc.

Damper Control.—Both the grates and the draft of a well-proportioned boiler plant are designed to burn the maximum amount of fuel per unit of time under conditions of maximum load. If the draft were allowed to operate free and unobstructed all the time, it would be impossible to vary the load from the maximum load. For this reason, means must be provided to vary the draft as necessary. A suitable damper should be placed in the uptake or in the breeching leading from each boiler, and it should be arranged so that it can be operated by means of a system of levers from a convenient point near the furnace door. These dampers should be arranged so that they cannot be closed fully or closed sufficiently to cause the furnace to smoke. The smoking point can be determined by gradually closing the damper and watching the stack for smoke. If several boilers are connected to the same stack, the dampers should be set so that each boiler will carry its proper share of the load. If this is not done, the boiler nearest the stack will operate at or above its greatest capacity, while the boilers farther away will operate at reduced capacities, depending on their distance from the stack.

The duty of the damper is to check the rate of combustion to suit the varying conditions of the load. Much fuel can be saved by a proper manipulation of the dampers, and as much intelligent care

should be exercised in their operation as is taken in firing the coal. The ash-pit door should be kept wide open, and the draft should not be regulated by closing the door unless the damper in its closed position does not sufficiently retard the draft. Closing the ash-pit door shuts off the supply of air through the firebed and increases the tendency for leakage of air into the breeching, etc. through cracks and other defects. This results in smoke, in almost a complete loss of the gases of the coal as they are roasted out, and in a further loss through heat absorption by the air that leaks in. Regulating the draft by means of the damper decreases the tendency for air leakage and gives free access for the air through the fire.

If the ash-pit door is entirely closed, it so shuts off the air supply through the fuel bed that the grate and the ash becomes overheated. This eventually results in warped grates. Also, the increased temperature tends to fuse the ash and to cause the formation of clinker.

Draft Gauges.—Each boiler of a power plant should be fitted with draft gauges conveniently placed for easy reading by the fireman. One, should indicate the draft in the furnace over the fire, and another the draft in the breeching or the chimney. The first will thus indicate the "drop" of draft through the fire, while the second will indicate the "drop" through the tubes, etc. When the fireman is familiar with the amount of draft required with a clean fire and clean tubes, he can readily note any change in the fire or tube conditions by means of the draft readings. An increase in the drop of draft through the fire indicates a fire that is becoming either dirty, coked or too thick; a decrease in the drop indicates a fire too thin or one that has holes

or cracks in it. Increased drop between the furnace and the uptake indicates increased friction, due probably to deposits of soot, ash, etc. upon the tubes and the baffles. Decreased drop indicates reduced friction; possibly the baffling has burned out or broken down, thus allowing the gases to short-circuit.

When several boilers are in a battery, their dampers should be adjusted until the draft gauges indicate equalized drafts, so that each boiler will carry its share of the load.
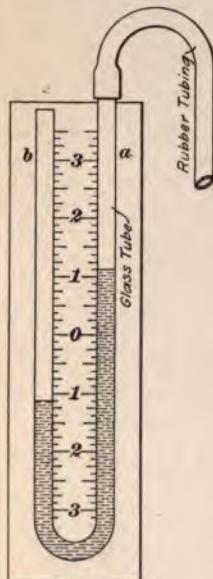
Fig. 13.
Water Draft Gauge.

A simple form of U-tube draft gauge is shown in Fig. 13. The arm *a* has attached to it a flexible rubber tube that leads to the point at which the draft is to be measured. The arm *b* is open to the atmosphere. The tube is filled with water to the zero reading on the scale when both the arms *a* and *b* are open to the atmosphere. When the arm *a* is connected up for draft readings, the pressure in that arm is less than atmospheric pressure, owing to the draft; therefore, the water is raised on that side and lowered in the arm *b* until a balance is reached. The difference in the heights of the two columns represents the amount of pressure that the atmospheric pressure exceeds the pressure at the point at which the draft is being measured. Each inch difference in height is equivalent to a pressure of .578 ounce per square inch. The gauge in Fig. 13 indicates 1.125 inches below the zero mark on the arm *b* and 1.125

inches above zero on the arm a, or a total of 2.25 inches. This represents a pressure of $2.25 \times .578 = 1.3$ ounces per square inch. The readings above and below the zero mark are added for the total, whether they are equal or unequal. Table XXXII gives pressures corresponding to various differences in the heights of the two columns of water.

TABLE XXXII.

Draft-Gauge Pressures Corresponding to Various Heads of Water.

Head, Inches	Head, in Parts of an Inch									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	. . .	.06	.12	.17	.23	.29	.35	.40	.46	.52
1	.58	.63	.69	.75	.81	.87	.93	.98	1.04	1.09
2	1.16	1.21	1.27	1.33	1.39	1.44	1.50	1.56	1.62	1.67
3	1.73	1.79	1.85	1.91	1.96	2.02	2.08	2.14	2.19	2.25
4	2.31	2.37	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
5	2.89	2.94	3.00	3.06	3.12	3.18	3.24	3.29	3.35	3.41

A mechanical draft recorder for making permanent, continuous records of all changes in draft is shown in Fig. 14, and a draft-pressure record is shown on the chart. This gauge is a product of the Crosby Steam Gauge Company. By its use, continuous records of all changes in draft that occur during a run may be obtained and filed away for future reference. The record gives a valuable check on the way in which the fire under a boiler is manipulated.

OBSERVATION AND ESTIMATION OF SMOKE

The plan most generally adopted for estimating the relative blackness of smoke and for recording the length of time during which smoke of varying degree of blackness is emitted from chimneys is that devised by Professor Ringelmann, of Paris, and re-
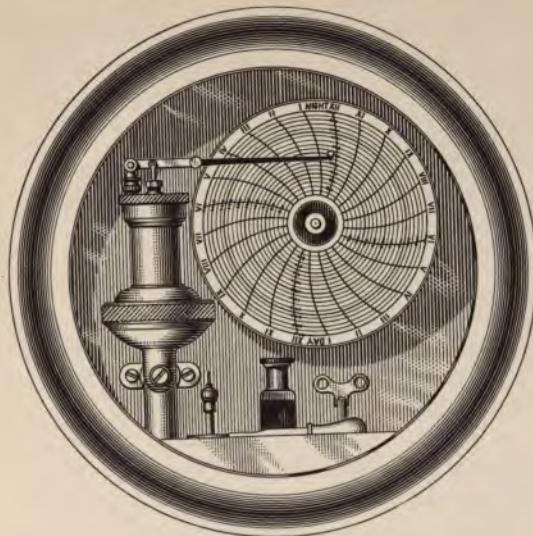
Fig. 14.
Recording Draft Gauge.

ported in the Transactions of the American Society of Mechanical Engineers, Vol. XXI, Dec. 1899. The plan requires six cards similar to those shown in Fig. 15, the cards in the illustration being very much
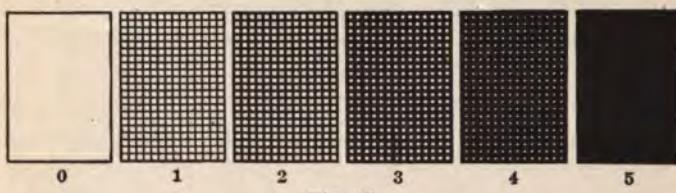
Fig. 15.
Scale for Grading Smoke Density.

reduced in size. The cards are white with black lines, and are placed in a horizontal row, as shown. They are numbered from 0 to 5. Card 0 is all white. Card 1 has lines 1 mm. (millimeter) thick and 10 mm. apart, leaving spaces 9 mm. square. Card 2

has lines 2.3 mm. thick, 10 mm. apart, and spaces 7.7 mm. square. Card 3 has lines 3.7 mm. thick, 10 mm. apart, and spaces 6.3 mm. square. Card 4 has lines 5.5 mm. thick, 10 mm. apart, and squares 4.5 mm. square. Card 5 is all black.
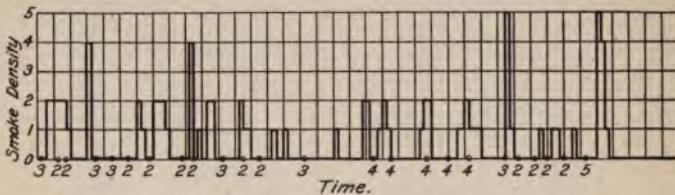
Fig. 16.
Result of Tests Plotted for Density of Smoke.

The rows of cards are hung in line with the chimney under observation at a point about 50 feet distant from the observer, at which distance the lines of the cards become invisible and the cards appear to be of different shades of gray, ranging from very light gray to almost black. The observer glances alternately at the smoke and at the cards, makes observations continuously for 1 minute, and decides which card most nearly corresponds with the color of the smoke. The record is then made accordingly, noting the time. The color recorded in the estimated average density of the smoke during the entire minute, and records are made for each consecutive minute during the test. The average of all the records made during the boiler test is taken as the average figure for the smoke density during the test, and the whole of the record is plotted on cross-section paper, Fig. 16, to show the variations in the density of the smoke from time to time. The numbers at the left represent the scale of the smoke density, while the time scale is laid off on the horizontal.

CHAPTER XIX

BOILER PLANTS for SMOKELESS COMBUSTION

HAND-FIRED FURNACES

B Y far the greater number of steam plants throughout the country are fired by hand. As a general rule, however, they are of comparatively small total horsepower, ranging from 50 to 500 horsepower. In some instances they total 1,000 horsepower, but usually mechanical stokers are used in the larger power plants. A large majority of hand-fired plants are persistent smoke producers, due principally to improper furnace construction for the coal burned and to lack of proper mixing devices for mixing the air and the gases. In such plants, the best that can be done is to use a low-volatile or smokeless coal if practicable, to fire carefully and intelligently, to keep a clean fire, and to crack the firedoor for a short interval after each firing. Numerous devices have been patented for the prevention of smoke in hand-fired furnaces, but most of them have proved to be dismal failures on account of their violating the principles of combustion.

Firebrick mixing piers and arches have been tried, but they have not been used extensively, owing to the difficulty of procuring materials that will withstand the intense heat to which they are subjected. Also, the piers and arches diminish the combustion space, which, generally, is none too large, and they increase the resistance to the flow of gases, thereby reducing the available draft and the capac-

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ity of the furnace. However, there are a number of very good hand-fired furnaces that give excellent service with very little smoke when properly operated with suitable coal. Among them are the Haw-
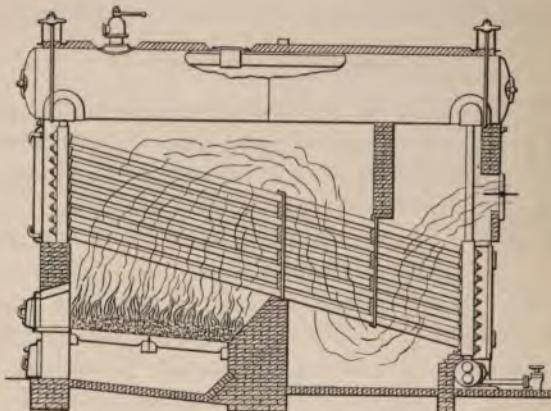
Fig. 17.
Plain Furnace, Babcock & Wilcox Boiler.

ley down-draft, the Dorrance, the Wooley, the Burke, the Twin-arch, the Dutch Oven, the Puddington, and others.

Plain Furnace.—A plain furnace under a Babcock & Wilcox boiler is shown in Fig. 17. The furnace is situated within the walls of the boiler. Since no provision for smokeless combustion is made in this furnace, it is adapted only to anthracite, semianthracite, or short-flame semibituminous coals. It is very efficient for such coals, on account of using the direct radiant heat of the fire. If an attempt were made to burn bituminous or subbituminous coals in this furnace, dense, black smoke would result, as indicated in Fig. 18. The flame is extinguished when it strikes the tubes, allowing the car-

bon that has been liberated as soot to pass off in a dense, black cloud. This not only wastes the fuel value of a large percentage of the gases of the coal, which pass off unburned, but also waste the heat
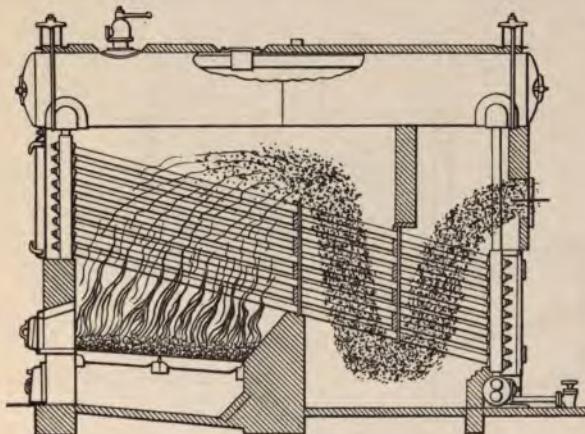
Fig. 18.
Furnace Unsuitable for Bituminous Coal.

absorbed by the gases, owing to the non-conducting properties of the soot that is deposited in the tubes and thus reduce the absorption of the heat.

The furnace arrangement shown in Fig. 12 is a good one for burning high-volatile coals smokelessly under return-tubular boilers. The furnace arch does not extend forwards over the grate, so that the boiler receives heat by direct radiation from the fire, thereby increasing the efficiency of the boiler. Also, this cools the furnace temperature somewhat and so reduces the tendency for the ash to clinker because of too high furnace temperature.

Dorrance Furnace.—The Dorrance furnace under a Babcock & Wilcox boiler is shown in Fig. 19. The furnace extends in front of the boiler and is

virtually a Dutch oven with a long arch sloping toward the rear of the furnace. The arch covers the entire grate and extends back into the combustion space; hence, there is no direct radiation of the heat of the fire to the heating surface of the boiler.
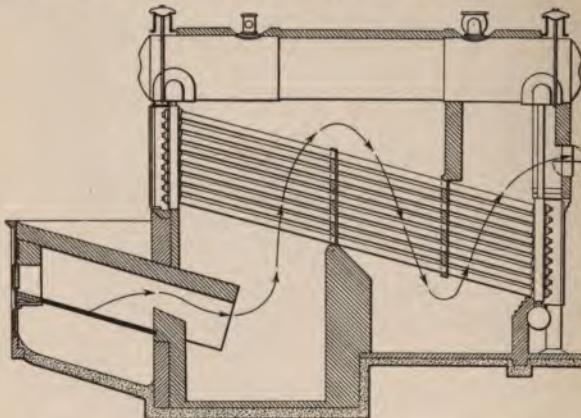
Fig. 19.
Hand-Fired Dorrance Furnace, Babcock & Wilcox Boiler.

The grate also slopes toward the rear of the firebox. The arch in this construction maintains a high, even temperature, while the constriction at the bridge wall and the lower end of the arch tends to mix the air and the gases of combustion, thereby shortening the length of the flame and promoting smokeless combustion. The minimum distance from the grate to the tubes is sufficient for the flame from most coals.

Wooley Furnace.—The Wooley furnace, Fig. 20, also extends in front of the boiler. A sectional view of the furnace, Fig. 21, shows the form of the mixing wall and the two openings through it, a portion being broken away to show the openings. This is a firebrick wall with a projecting angle for splitting

the gases so as to facilitate their movement through the two openings at the face of the wall. The constriction at the bridge, the splitting of the gases, their passage through the two openings and their
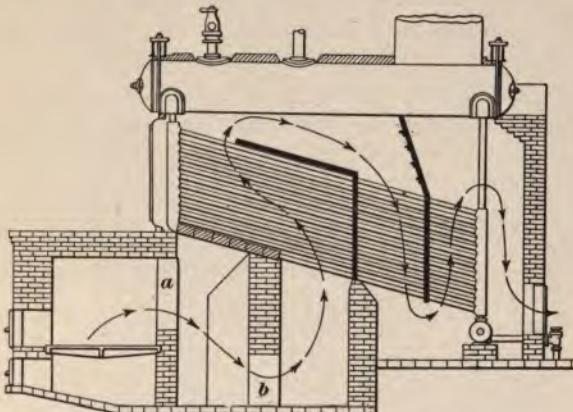
Fig. 20.
Hand-Fired Wooley Furnace and Babcock & Wilsox Boiler.

coming together again, all tend to assist the mixing process. The minimum path for the gases from the grate to the tubes is such as to provide sufficient
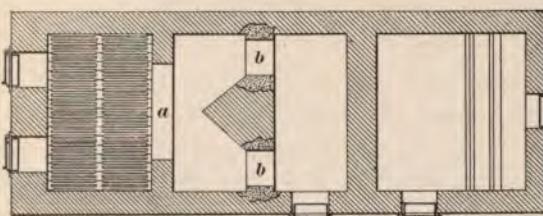
Fig. 21.
Wooley Furnace Plan.

space for burning the gases of most coals smoke-lessly.

Hawley Down-Draft Furnace. — The Hawley

down-draft furnace, Fig. 22, has two separate grates, as shown. On account of the high temperature to which the upper grate is subjected, it is in the form of a water grate. The lower grate is of common gratebars. The coal is fired on the upper grate only, and the air enters through the upper firedoors and passes downwards through the fire to the space between the two grates. The lower grate is fed from partly consumed fuel falling from the upper grate.
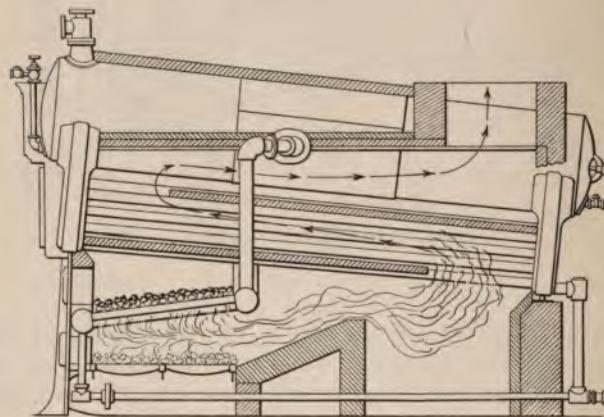
Fig. 22.
Hawley Down-Draft Furnace, Heine Boiler.

Air for burning this fuel and for burning the gases from the upper fire bed enters from below the lower grates. The air and gases from the fresh coal are heated in passing through the fuel bed, and are intimately mixed and burned in the combustion space, as indicated. The horizontal baffle, extending over the grate and back into the combustion space along the lower row of tubes, lengthens the minimum path of the flame to the tubes the proper amount for smokeless combustion.

The furnace in the illustration is shown built within the boiler setting. In many cases, however, it extends in front of the boiler.
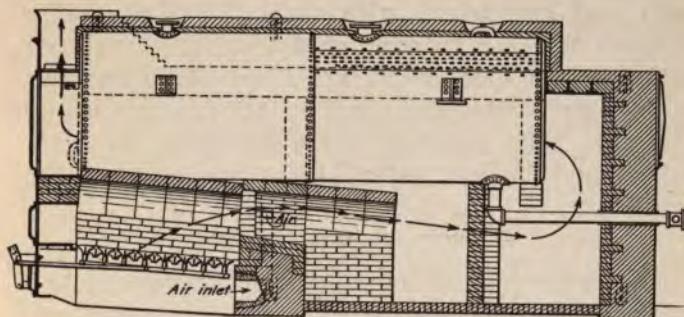
Fig. 23.
Hand-Fired Twin-Arch Furnace and Return Tubular Boiler.

Twin-Arch Furnace.—The twin-arch furnace, shown under a return-tubular boiler in Figs. 22 and 24, promotes smokeless combustion through the use of special arches and mixing piers. It consists of
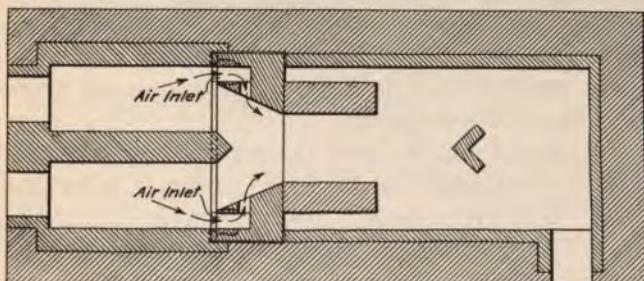
Fig. 24.
Hand-Fired Twin-Arch Furnace Plan.

two furnaces, each with its own arch, so that they virtually form two Dutch ovens. Back of this there is a single cone-shaped arch, with air-admission

openings. Another arch is built back of the cone-shaped arch, and a V-shaped mixing pier is built farther back in the combustion space. The gases from the two furnaces mingle in the cone-shaped arch and are mixed with fresh air that enters through the air-admission openings. The rear arch acts as a mixing chamber. After the gases are mixed they expand and are split into two streams by the pier, thus insuring the gases being properly mixed and burned before the flame reaches the tubes.

METHODS OF HAND FIRING

Four methods of hand-firing are in more or less general use. They are known as the coking method, the ribbon method, the spreading method, and the alternating method.

Coking Method.—The coking method of firing is best adapted for coking coals and for coals rich in higher hydrocarbons and tarry vapors and where the demand for steam is fairly regular. It is not a very flexible method; therefore, it is not suitable for conditions under which the load varies quickly and calls for a quick, heavy demand for steam. For the reasons mentioned it is not so widely used in practice as the other methods.

In the coking method, the coal is first piled on the dead-plate near the firedoor, where it is heated slowly. This gives a slow, uniform evolution of the gases. The furnace door should be perforated with a number of air-holes, and should have a means of regulating the air supply through the door. As the gases are roasted out of the coal, the air, which enters in small streams through the firedoor, mixes with the gases, and the gases are completely burned while passing over the glowing coke on the grates.

When the coal has been thoroughly coked, it is pushed back onto the grates and spread evenly over the surface, care being taken to fill any thin spots or holes in the fire. A new charge is then put on the dead-plate. Since large lumps coke slowly, they should be broken up before being placed on the dead-plate; also, as the coal cokes and forms a crust, the crust should be broken up as frequently as is necessary.

Ribbon Method.—In the ribbon method of firing, the coal is fired alternately in narrow strips across the entire length of the grate. The coal should be fired frequently and in small amounts, cracking the fire door for a short interval after each fire if automatic air admission is not used. This method gives a very high efficiency and practically no smoke. It is well adapted for burning high-volatile coals.

Spreading Method.—The spreading method of firing is probably the most commonly used system of any. However, with smoky coals, it is the least efficient method, and it produces the most smoke. It is best adapted for the larger sizes of anthracite, semi-anthracite, or high-grade bituminous coals, but requires very careful firing for good results, even with such coals.

The method consists in spreading the fresh coal evenly over the whole grate in a thin layer. The fresh coal lowers the temperature of the furnace, and if the layer is too thick it may lower the temperature so much that a large part of the gases will pass off unburned, resulting in a large heat loss and in the production of much smoke.

Alternate Method.—The alternate method of firing is the second only to the spreading method of

firing. It is best adapted for non-coking coals, and when properly used it will give excellent satisfaction, even with coals rich in volatile matter.

For small furnaces, the coal is fired lengthwise on the grate, spreading the coal alternately on each half of the grate. When the grate area is large, it is divided into four or six equal parts, depending on the size of the grate. The fresh coal is fired alternately on one-half of these areas, the time interval of firing varying to suit the demand for steam. This method always leaves half of the fire bright, to furnish the heat required to burn the gases. Also, the air enters through the bright half of the fire more freely than it does through the thicker half, thereby furnishing the air needed for the consumption of the gases.

Burning Slack.—Slack coal is coal that will pass through a 4-mesh-per-square-inch screen. The evaporative value of a coal decreases with the percentage of slack it contains. A coal that with 10 per cent. of slack will evaporate 8 pounds of water, with 30 per cent. slack will evaporate only $6\frac{1}{2}$ pounds, and with 70 per cent. will evaporate only about $5\frac{3}{4}$ pounds.

To burn properly a coal that contains much slack requires skill on the part of the fireman and much hard work. Slack has a strong tendency to fuse and cake into a hard crust, which prevents the passage of air through the fire, except where the crust cracks. The effect of this is to reduce the capacity of the boiler greatly, unless the crust is broken up to let the air through. The more coal fired at a time, the thicker will be the crust that forms; hence, slack should be fired in small amounts and frequently. When so fired, there will form only a light crust that will burn through in a very short time. If necessary,

this crust can be readily broken through with the careful use of the rake without having to resort to the slice bar, the use of which is apt to cause clinker by raising some of the ash up into the hot zone of the fire. In using the rake, it should rest on the firedoor frame; also, the prongs of the rake should be carefully inserted only through the crust, so as not to disturb the ash and cause clinker.

Precautions in Firing.—Keep the fire level and as thin as the character of the coal and the strength of the draft will permit.

Keep the fire level by spreading the fresh coal, as it is fired, over the thin spots. Filling up hollows by firing a heap into the thin spot may cause clinker. It is quite sure to result in a high spot.

Fire the coal in small quantities and at short intervals. If fires are too far apart, thin spots and holes in the fire may result.

Avoid disturbing the fire; it is unnecessary work and may cause clinker. Also, the excess air through the open furnace door reduces furnace temperature, causing a loss of heat. If the rake must be used to level the fire, use it carefully, so as to avoid lifting ash up into the hot zone of the fire, as it will form clinker. Avoid the use of the slice bar.

Keep ash-pit doors open and avoid accumulations of refuse in the ash-pit. This will result in better furnace economy, will help prevent the grates from warping, and will tend to avoid clinker.

At the first signs of clinker formation, keep water in the ash-pit or use ash-pit steam jets, if provided.

In firing green coal on holes in the fire, select coal large enough; fine coal will drop through the

grate and burn in the ash-pit. Burning coal in the ash-pit warps the grates, and causes clinker.

If neither automatic nor non-automatic air regulation is provided, crack the firedoor for a short time after each fire.

The tendency for a coal to coke, or fuse, and thus form a crust is greatly reduced by firing small amounts frequently and spreading the coal in a thin sheet over the fire.

Regulate the draft by using the damper in the uptake or breeching, and not by closing the ash-pit doors. Close the damper gradually—just a sufficient amount to get the effect desired. Avoid closing it suddenly the full amount, as this will produce dense, black smoke.

Cleaning the Fire.—Cleaning the fire consists in thoroughly removing all clinker and refuse from the grates, and it must be done in such a way as to waste as little combustible as possible. Cleaning is best accomplished by first separating the good coal from the refuse that is below the good coal and next to the grates.

The condition of the fire at cleaning should be such that there will be sufficient fire in the furnace to start a good, hot fire as soon as the cleaning is completed. If there is not sufficient fire for this purpose, the fire should be built up to the proper amount before the cleaning is begun. If the fire is too thick, the work will be much more difficult; therefore, such a fire should be allowed to burn down to the proper amount before starting to clean it. During the cleaning, the damper should be partly closed to avoid the rush of too much cold air through the furnace and tubes.

The hoe and the slice bar should be used to move the burning coal from the left half to the right half of the grate, or vice versa, and the left half should then be thoroughly cleaned of all ash and clinker. If any clinker sticks to the grate or side walls, it can be loosened or broken by means of the slice bar so that it may be removed with a hoe. The clinker is removed through the firedoor and dumped into a barrow or some other conveyance.

When the left side is cleaned, all the burning coal should be moved to that side and spread evenly over the clean part of the grate, and sufficient fresh coal added to the fire to insure enough burning coal to cover the entire grate after the right side is cleaned. The right side should next be cleaned, after which the fire should be spread over the whole grate and build up as desired by the addition of fresh coal.

If the fire must be cleaned quickly during the time of heavy load, the fire should be pushed back and piled up against the bridge wall and the entire grate, except that portion on which the coal is piled, cleaned at the same time. The coal should then be pulled forwards onto the clean grate and fresh coal added as required. This method should be used only as an emergency method, and the fire should be properly cleaned when the load on the boiler will permit.

Banking the Fire.—Where a fire is to be banked overnight, the burning coal should be banked on the front part of the grate in either corner, and the damper should be almost closed. Banking the fire in the front instead of at the bridge wall, allows the clinker near the bridge wall to cool off overnight. The clinker and refuse should be allowed to remain on the grate until the following morning, as it helps maintain the furnace temperature. Also, it will be

cool by the morning and can then be more readily removed. After the grate is cleaned, the fire should be spread over the clean part, and the refuse that was under the bank should be removed. The fire should then be spread over that part of the grate, and the fire built up as required.

<center>STOKER FURNACES</center>

Mechanical stokers operate automatically, but this does not mean that they will take care of themselves under all conditions and will not require any attention. For successful operation, a stoker requires the attention of one expert in the operation of the type of stoker used. There are two objects in the use of the mechanical stoker. One, is to reduce labor in the boiler room; the other, and chief object, is so to regulate the supply of coal and air to the fire that the coal will be burned with maximum economy and will produce a maximum boiler capacity at a maximum efficiency and with the least smoke. Stokers under ordinary operating conditions will operate with less smoke than hand-fired furnaces, provided they are supplied with the proper class of coal. A stoker will not handle all classes of coal equally well; therefore, care should be exercised to select the proper stoker for the coal to be used, or vice versa.

Stokers are of three types—the traveling grate, the overfeed, and the underfeed. The overfeed type is subdivided into front-feed and side-feed stokers. The traveling-grate type is commonly known as the chain-grate stoker.

<center>TRAVELING GRATE STOKERS</center>

Chain-Grate Stokers.—The chain-grate stoker is illustrated diagrammatically in Fig. 25, in connection with a Babcock & Wilcox boiler. The coal is

fired into a hopper that extends the entire width of
the grate and feeds the coal onto the grate.   The
regulating plate 2 also extends the width of the
grate, and its duty is to regulate the thickness of fire
carried on the grates.   The grates are endless and
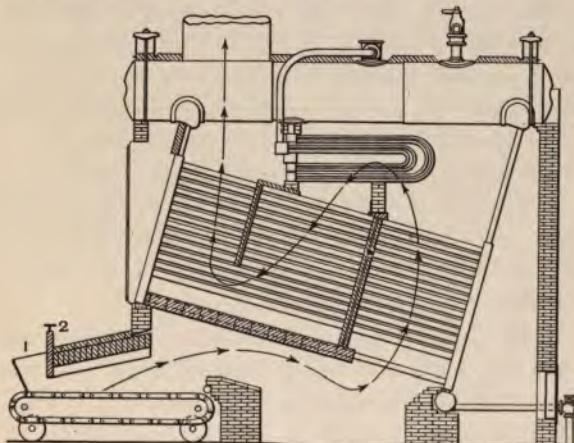
Fig. 25.
Chain-Grate Stoker, Babcock & Wilcox Boiler.

revolve continuously from the front toward the rear
of the furnace, the speed being regulated as desired.
The grate is horizontal, except in special cases, when
it is inclined slightly toward the rear, as with low-
set tubular or water-tube boilers, where it is inclined
in order to get the necessary head room at the rear
of the firebrick ignition arch.   The ignition arch
extends backwards and upwards from the hopper,
the length varying somewhat with the different
makes of chain grates.   Its height above the grate
at the hopper end varies from about 11 to 13 inches,
while the height of the other end varies from about
15.5 to 26.5 inches.   The slope of the arch depends
somewhat on the strength of the draft; the stronger

the draft, the less the slope. Too great a slope for the draft of the stack will cause the furnace to smoke. The length and slope of the arch are generally proportional to the draft and to the kind of coal that is to be burned.

The stoker operates continuously, feeding the coal into the furnace, igniting and coking it, consuming all the combustible matter, discharging the refuse into the ash-pit, and automatically keeping the air spaces in the grate clear of clinker. This obviates the necessity of opening the firedoor, be it for firing, for clearing the fire, or for removing refuse. The minimum length of the flame before it strikes the lower tubes is regulated by the length of the bottom baffle, as shown.

This type of stoker is best adapted to burning non-coking coals, and will give good satisfaction even with the poorest grades of high-ash coal. The size of coal generally used is slack, screenings up to 2-inch, pea and slack, and nut and slack. The depth of fire carried varies from 4 inches to 7 inches, and averages about 4.5 inches. This type of stoker is used most extensively with water-tube and plain boilers, and frequently with return-tubular boilers. It gives best service with plants that maintain fairly uniform loads, and with proper management it will operate under variable loads with but little smoke. If improperly operated under varying loads, it will produce dense, black smoke.

The cost of upkeep of a chain-grate stoker properly operated is low in comparison to the cost of the upkeep of other types of stokers. Also, it has another decided advantage in that it can be withdrawn from the furnace for inspection or repairs without in any way interfering with the boiler setting.

Operation of Chain-Grate Stoker.—Coal burned in a stoker is consumed under conditions similar to those which obtain in the coking method of hand-firing. Green coal enters the furnace from the hopper; for a distance back on the grate, the coal is in varying stages of distillation; back of this there is a solid bed of burning coke of varying depth, that in the front being fresh coke. The thickness of the fire progressively decreases from the front backwards, due to the varying length of time that the coke has been burning, until at the end of the grate nothing but refuse remains. Air for the combustion of the gas enters through the thin fire in the rear of the grate. The speed of the grate should be such as will maintain the condition of the fire over the grate constant for that rate of combustion. If the speed is too fast for the thickness of the fire carried, the coke will not be completely burned by the time it is dumped into the ash-pit. This will result in a loss from incomplete combustion of the gases and from carbon in the ash, and in damage to the grates through warping and burning. The grate should never be run so fast that it will be hot when reentering the furnace. Carrying a heavier fire at a slower speed will give the same steam capacity with cool grates.

If the speed of the grate is too slow for the thickness of the fire, the fire will be entirely burned out long before it reaches the end of the grate. This will cause a considerable drop in the efficiency of the furnace, due to excess air through the ash.

Variations in the load should be taken care of by changing the thickness of the fire, the speed of the grate, and the position of the damper. Attempts to regulate by means of the damper alone will cause

dense, black smoke, owing to the too limited air supply for the rate of combustion.

Front-Feed Stoker.—A Roney type of front-feed stoker under a Heine boiler is shown in Fig. 26. In this type of stoker the coal is fed into a hopper at the front end of the furnace, which device delivers it onto the dead plate and to the grates. The grates
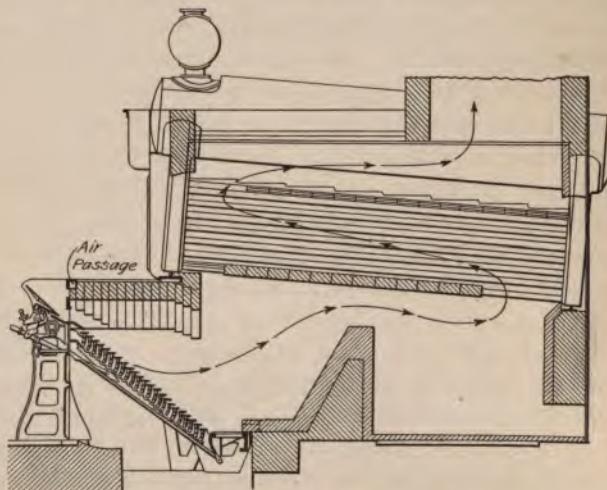
Fig. 26.
Roney Front-Feed Stoker, Heine Boiler.

are inclined downwards toward the rear at an angle of about 45 degrees and are mechanically operated, the grate bars being made to take alternately level and inclined positions at speeds varied to suit conditions. This movement of the grate bars causes the fuel as it burns to move downwards toward the bottom of the grate, where a flat dumping grate is supplied for the purpose of dumping and cleaning the

fire. The coal is coked on the dead plate and the top part of the grate, and the coke is progressively burned, because it is moved down the grate at such a rate that it is completely burned by the time it reaches the bottom, or dumping, grate.

Smokeless operation with this type of stoker requires careful operation. Also, to aid in smoke prevention, steam jets are provided in the air passage in the coking arch, as shown in Fig. 26, and an ample air supply is provided. The steam jets, when used, are in continuous operation.

The stoker is well adapted to forcing a fire quickly; hence, it provides a flexible fire for variable loads. It burns various sizes of coal, as screenings, slack, run-of-mine, pea, nut-and-slack, etc. The depth of fire carried usually varies from 3.5 to 7 inches, and averages about 4.5 inches. The frequency with which the fires must be cleaned varies from once every 2 hours to once every 14 hours, depending on the kind of coal and on the tendency of the ash to clinker.

Fig. 27 shows how Stoll and Finlay, Jr., of the Interborough Rapid Transit Co., of New York City, made use of a second Roney front-feed stoker in the rear of several Babcock & Wilcox boilers with a view of increasing the output of the plant, which was already installed. The front stoker had a grate area of 100 square feet, while the rear stoker had 80 square feet. The addition of the rear stoker almost doubled the amount of coal burned and the boiler absorbed nearly twice as much heat as with the single stoker.

Side-Feed Stokers. — Two makes of side-feed stokers in most general use are shown in Figs. 28 to 31, inclusive. Fig. 28 shows a cross-sectional

view of a Murphy stoker under a return tubular boiler; Fig. 29, a Murphy stoker in a Dutch oven and a Babcock & Wilcox boiler; Fig. 30, a Murphy stoker and a Heine boiler; and Fig. 31, a Detroit stoker and a Stirling boiler.
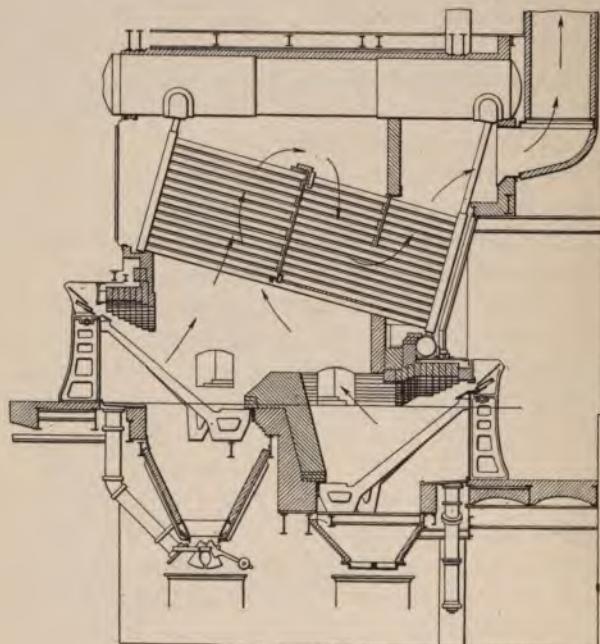
Fig. 27.
Roney Double-Stoker Plant.

The side-feed stoker differs from the front-feed stoker in that there are two sets of grates sloping downwards from the sides of the boiler, each side being fed by its own magazine *1*. At the bottom of the magazine there is a steel coking plate *2*, in which the coal-feeding mechanism *8* rests. Below this plate is the air duct *4*. The arch plate *3* supports the fire-

brick arch, which extends over the whole grate area. Above this arch there is a hot-air duct 5, with openings 6 into the combustion space. These openings admit hot air at a point just above the coking coal, so that the air and the gases mix intimately as the gases are given off. The stoker boxes 8 are operated by shafts rotating through a small arc. The shafts move the boxes forwards, so as to push the coal that is in the front of them onto the grates for coking. A hollow iron bar 9, with projections on its surface and supported by a shaft, forms the clinker-breaking device. This device and the movable grates are operated by a small engine that is part of the equipment. When the bar is rotated it grinds up the clinker.
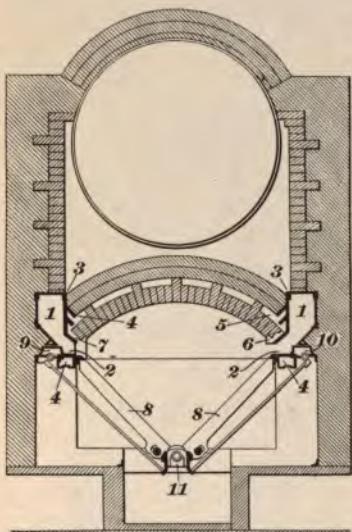
Fig 28.
Murphy Side-Feed Stoker,
Return Tubular Boiler.

The Detroit stoker, Fig. 31, feeds the coal by means of a screw feed 1. The clinker-breaking device consists of heavy iron disks 2 operated by means of reciprocating bars 3.

The large combustion space in the furnace between the grates, assists very materially in obtaining complete combustion without smoke. Also, the

large coking-plate area allows a boiler to be started up from a banked fire and thrown into service without much smoke.
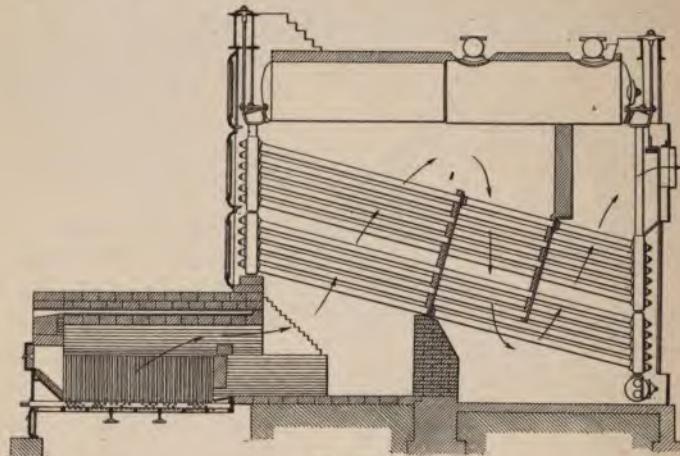
Fig. 29.
Murphy Side-Feed Stoker, Dutch Oven.
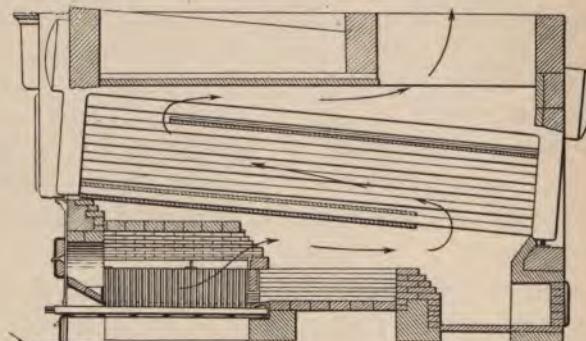
Fig. 30.
Murphy Side-Feed Stoker, Heine Boiler.

This type of stoker is used very extensively under return-tubular boilers and under water-tube boilers. It successfully burns slack, nut-and-slack,

nut, and run-of-mine coal. The depth of fire carried
under water-tube boilers varies from 4 to 7 inches,
with an average of about 5.5 inches.   In return
tubular boilers, the depth varies from 5 to 11 inches,
with an average of about 6 inches. The stoker gives
good satisfaction in both small and large plants, and
under both uniform and variable loads.
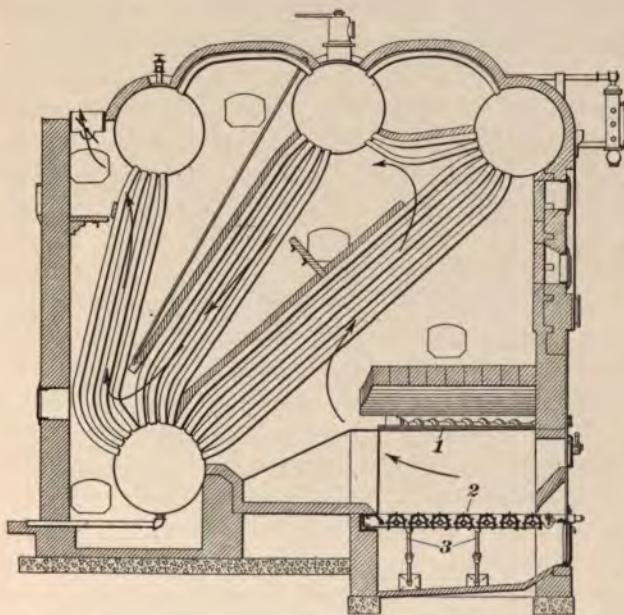
Fig 31.
Detroit Side-Feed Stoker, Sterling Boiler.

UNDERFEED STOKERS

Two makes of underfeed stokers, the Jones type
and the American type are in use under power plants.
They differ chiefly in the feeding mechanism and in
the device for handling the burning coal after it
leaves the retort. In the Jones stoker, the coal is

intermittently pushed beneath the burning coal in the retort by means of a ram actuated by a cylinder. In the American stoker, the coal is forced continuously into the retort by means of a cone-shaped screw.

The Jones stoker and a Heine boiler are shown in Fig. 32, and in Fig. 33 is shown a cross-section of this same stoker in connection with a return-tubular boiler. It consists of a steam cylinder, or ram, *1*, a hopper *2* for holding the coal, and a retort *3* inside the furnace, into which the coal is forced by a ram and above which it is coked. Tuyère blocks *4* ranged around the sides and ends of the retort, having openings *a* through which air for the combustion of the coal is forced. At the bottom of the retort, covered by green coal, a ram or pusher *6*, Fig. 33 operates, and it is by means of this that an even distribution of the coal is made in the retort. The ram forces the green coal underneath the coal that is already coking in the retort, each charge raising the preceding charge upwards until, finally, it reaches the fire after being thoroughly coked. The coked coal rolls down the sides of the heap and falls on the dead plates *7*, where combustion is completed, the air being supplied through the tuyère openings. Air at a low pressure (from $\frac{1}{2}$ to 1 ounce) is supplied to the closed air chamber *8* by means of an independent air blower, and it passes into the tuyère blocks through the opening in the bottom of the blocks. The green coal in the retort is so compact that the air takes the path of least resistance and passes upwards; consequently, combustion takes place only above the air slots, and the retort is not subjected to the action of the fire. The gases are liberated slowly under the burning coal, and, in passing

upwards, they are intimately mixed with the air from the tuyère openings and so highly heated that their combustion is completed within a short distance from the top of the burning coal. This results in a bright fire, free from smoke. For the reason stated, less combustion space is required with this type of stoker than with any other. The stoker, as can be seen, is very compact and requires but a very small space above the grate.
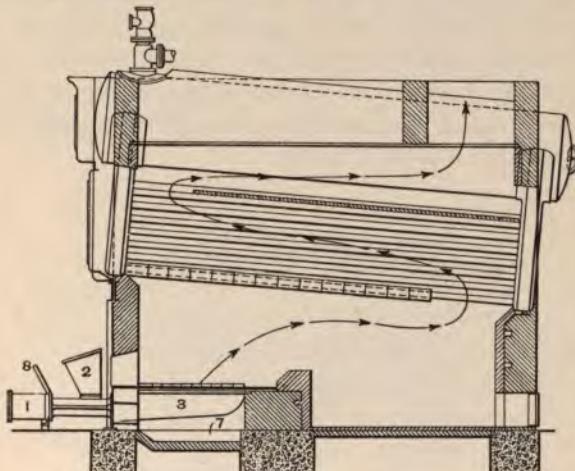
Fig. 32.
Jones Stoker and Heine Boiler.

On account of using a blower, the air regulation can be anything desired, so that a much smaller stack will be satisfactory with an under-feed stoker than with the other types using natural draft. Also, where the stack capacity of a plant has been reached, the capacity of the boiler plant can be increased by the use of underfeed stokers without any stack changes.

The ram is operated by means of the lever *8*,

Fig. 32. By shifting the lever, the coal in front of the plunger is forced into the retort. When the plunger is returned to its original position, more coal falls in front of it for the next charge. The charges are fired as frequently as required.

This type of stoker is used under both return-tubular and water-tube boilers, the newer installations being fitted with automatic control for both the coal and the air. This stoker uses the same sizes of coal as the other stokers, but will give best service with low-ash coals. With return-tubular boilers, the depth of fire varies from about 12 to 18 inches; with water-tube boilers, it varies from about 8 to 18 inches. The stoker works successfully under both uniform and variable loads.
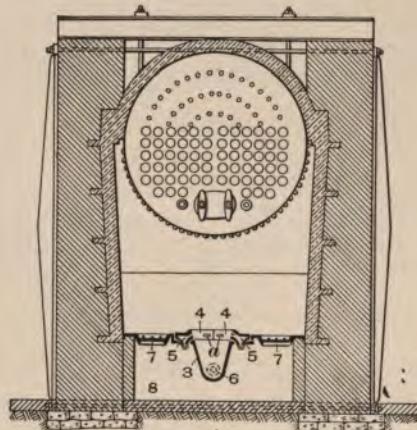
Fig. 33.
Jones Under-Feed Stoker, Cross-Section.

It is necessary to clean the fire in some cases very frequently, depending on the quality and the quantity of the ash in the coal. In water-tube boilers, cleanings range from once every 3 hours to once

every 9 hours; in return-tubular boilers, they vary from once every 2 hours to once every 14 hours. In this type of stoker, the ash accumulates on the dead plates, where it is subjected to the high temperature of the fire; consequently, a great deal of the ash fuses and forms large clinkers that must be pulled out of the furnace by hand. Cleaning of the fires, therefore, generally results in considerable smoke.

APPENDIX

ANALYSIS OF 319 AMERICAN COALS.

TABLE A

Analyses of 319 American Coals, "Air-Dried" Basis, With Calorific Value and C: (O+ash) Ratio of Each Coal.

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash.
1	Mass. 1	Halifax	P.	1.40	0.58	5.55	40.78	30.95	20.74
2	N. Dak. 1B	Lehigh	L.	0.55	3.95	5.57	44.11	33.07	12.75
2a	Mont. 3701	Nr. Miles	S.	.65	.66	4.51	48.01	28.17	18.00
2b	Wyo. 3694	Labarge Range	S.	.85	.61	4.45	48.65	38.57	6.87
3	N. Dak. 3	Wilton	L.	1.39	1.32	5.88	47.45	35.08	8.88
4	Ark. 10	Lester	L.	.91	.65	5.60	48.51	31.36	12.96
4a	Mont. 3816	Nr. Glendive	L.	.65	1.55	5.63	48.55	34.21	9.41
5	N. Dak. 2B	Williston	L.	.88	.71	5.66	50.79	35.86	6.10
6	Fla. 1	Orlando	P.	2.56	.49	6.06	51.18	34.03	5.68
7	Tex. 1	Crockett	L.	.95	1.04	5.57	52.06	25.53	14.85
8	N. Dak. 1	Lehigh	L.	.71	2.02	5.22	52.66	27.15	12.24
9	Wyo. 3	Aladdin	B.	.72	6.86	5.03	49.59	20.60	17.20
9a	Wyo. 3892	Fall River	S.	1.40	2.85	4.70	52.58	23.72	14.75
10	Ind. T. 5	Lehigh	B.	1.22	4.06	4.18	52.39	12.40	25.75
11	Cal. 1	Telsa	S.	.73	3.40	5.32	52.83	20.41	17.29
12	Mo. 7C	Noringer	B.	.98	3.47	3.95	53.55	10.48	27.57
12a	Wyo. 2326	Unita Co.	S.	.88	4.78	4.86	52.53	19.60	17.35
13	N. Dak. 2	Williston	L.	.91	.63	5.61	55.16	30.98	6.71
14	Ill. 2	O'Fallon	B.	.78	4.30	4.57	54.06	12.13	24.10
15	Mo. 7A	Noringer	B.	1.01	3.46	4.65	54.30	14.23	22.35
16	Mo. 3	Mendota	B.	.92	4.13	4.52	54.79	12.34	23.30
17	N. Mex. 2	Gallup	S.	.98	1.30	5.05	56.71	16.74	19.22
18	Wyo. 2	Cambria	B.	.80	4.17	4.54	55.29	12.94	22.26
19	Tex. 2	Hoyt	L.	1.06	.71	5.28	57.31	25.83	9.81
20	Wyo. 2B	Cambria	B.	.85	4.22	4.59	55.84	12.72	21.77
21	Mexico	....	B.	1.02	.96	3.97	58.97	6.36	29.33
22	Tex. 4	Hoyt	L.	.97	.70	5.06	58.83	24.48	9.96
23	Mo. 10	Bevier	B.	.97	4.28	4.05	57.25	9.69	23.76
24	Tex. 3	Olsen	L.	1.18	1.30	5.13	58.43	23.66	10.30
25	Wyo. 1	Monarch	S.	1.09	.63	6.09	58.41	28.99	4.79
25a	Mont. 3512	Belt Dis.	B.	0.65	1.71	4.17	59.65	15.19	18.63

TABLE A—*Continued*

Analyses of 319 American Coals, "Air-Dried" Basis, With Calorific Value
and C: (O+ash) Ratio of Each Coal.

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Moisture	Fixed Carbon	Volatile Matter	C / O+ash	Calories	B.T.U.	Age	Formation	Remarks
13.60	18.72	46.94	0.79	4055	7299	Recent		
24.82	29.85	32.58	0.96	4321	7778	Tertiary	Fort Union	Car sample
15.12	36.54	30.34	1.04	a4432	7969	Tertiary	Fort Union	Countryb'k
10.88	40.15	39.15	1.07	b4468	8042	Cretaceous	Montana	Prospect
26.64	27.92	36.56	1.08	4498	8096	Tertiary	Fort Union	Mine; c. s.
19.13	32.54	35.36	1.09	4714	8485	Eocene	————	Oil rock
24.11	15.80	50.68	1.11	a4522	8140	Tertiary	Fort Union	Countryb'k
22.77	35.72	34.41	1.21	4922	8860	Tertiary	Fort Union	Car sample
13.19	24.30	56.83	1.28	4961	8930	Recent	————	Briquetted
13.40	29.00	42.75	1.29	5199	9358	Eocene	* * *	Mine; c. s.
15.42	33.51	38.73	1.31	5034	9061	Tertiary	Fort Union	Mine; c. s.
12.58	34.82	35.39	1.31	5108	9194	Cretaceous	Montana	Mine; c. s.
10.32	30.48	43.46	1.36	b5106	9191	Tert-Cret.?	Evanston	Sur.sample
5.74	37.05	31.46	1.37	5201	9362	Carbonif.	Coal Meas.	Slack
9.05	34.23	39.43	1.41	5275	9495	Tertiary	* * *	Mine; c. s.
2.48	38.78	31.17	1.41	5399	9718	Carbonif.	Coal Meas.	Slack
7.21	36.95	37.96	1.42	5261	9470	Tert-Cret.?	Evanston	Mine
16.73	39.49	37.10	1.46	5273	9491	Tertiary	Fort Union	Mine; c. s.
5.31	36.24	34.29	1.48	5471	9848	Carbonif.	Coal Meas.	Slack
7.41	38.12	32.12	1.48	5503	9905	Carbonif.	Coal Meas.	Nut coal
5.51	39.11	32.08	1.56	5506	9911	Carbonif.	Coal Meas.	Slack
8.13	37.83	34.82	1.57	5667	10202	Cretaceous	Mesaverde	Mine; c. s.
2.73	37.40	37.61	1.57	5758	10364	Cretaceous	Montana	Mine
10.66	40.11	39.42	1.60	5502	9904	Eocene	* * *	Mine; c. s.
4.64	35.35	38.24	1.62	5815	10467	Cretaceous	Montana	Mine
0.91	47.69	22.07	1.63	5920	10656	Unknown	* * *	
9.76	42.77	37.51	1.71	5682	10228	Eocene	* * *	Mine; c. s.
1.77	43.97	30.50	1.71	5857	10543	Carbonif.	Coal Meas.	Screening
9.88	43.65	36.17	1.72	5715	10287	* * *	* * *	Mine; c. s.
17.09	39.56	37.96	1.73	5753	10355	Tertiary	Fort Union	Mine; c. s.
4.57	50.65	26.15	1.76	5824	10483	Cretaceous	Kootenai	Mine sam.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
26	Ill. 7A	Collinsville	B.	0.99	4.63	4.73	57.43	14.00	18.22
27	Tenn. 11	Ozone	B.	1.13	.92	3.96	60.56	4.90	28.53
28	Mo. 7B	Noringer	B.	1.02	4.13	4.23	57.82	8.98	22.82
28a	Colo. 3856	Nr. Thompson's	B.	1.35	.60	4.86	60.49	13.23	19.47
29	Mont. 2	Fromburg	S.	1.14	.62	4.75	60.97	16.60	15.92
30	W. Va. 24	Gary	Sb.	.66	.55	3.33	62.36	3.97	28.77
31	Mont. 1	Red Lodge	S.	1.36	.76	5.25	60.41	20.00	11.22
31a	Colo. 3729	Carbon era	B.	1.30	.50	5.37	61.17	16.58	15.08
32	Colo. 1	Lafayette	S.	1.22	.58	5.75	61.13	24.95	6.32
33	Ill. 24A	Livingston	B.	.97	4.56	4.71	59.37	12.88	17.51
33a	N. Mex. 3811	W. of Putnam	S.	1.51	1.92	5.50	60.32	20.61	10.14
34	Ind. 20	Brazil	B.	1.16	2.17	4.63	60.96	11.09	19.09
35	Ark. 9	Bonanza	Sb.	1.28	1.04	3.59	62.49	5.70	25.90
36	Iowa 5	Charlton	B.	1.22	3.42	5.35	59.89	16.57	13.55
37	Mont. 3	Bridger	S.	1.09	.56	4.87	62.32	17.34	13.82
38	Ill. 27	Auburn	B.	1.01	4.50	4.93	59.88	14.38	15.30
39	Ill. 4	Troy	B.	1.17	1.34	5.33	61.79	18.32	11.85
39a	Wyo. 3699	Labarge Range	S.	1.09	1.14	5.39	62.05	24.56	5.77
39b	Wyo. 3780	N. E. of Hanna	S.	1.73	2.41	5.73	60.53	23.55	6.05
40	Ind. 3	Boonville	B.	1.18	5.24	4.83	59.58	12.09	17.08
41	Wyo. 4	Hanna	S.	.90	.29	5.42	62.68	23.23	7.48
42	Ill. 8	Paisley	B.	1.08	4.68	5.25	59.88	16.01	13.10
43	Mo. 1	Sprague	B.	.99	5.53	4.64	60.00	8.46	20.38
44	Ill. 6	Coffeen	B.	1.23	4.45	4.88	60.51	14.20	14.73
44a	Wyo. 3693	Labarge Range	S.	1.03	2.10	5.74	61.76	25.96	3.41
44b	Mont. 3515	Belt Dis.	B.	.69	3.80	4.02	62.51	9.16	19.82
45	Ill. 23A	Donkville	B.	1.04	4.58	4.55	60.93	10.94	17.96
46	Wash. 1	Renton	S.	1.30	.68	4.91	63.28	16.92	12.91
46a	Colo. 4050	Nr.Glenw'd Sp's	B.	1.58	.98	5.04	62.74	19.71	9.95
47	Ill. 21B	Troy	B.	1.24	1.17	5.14	62.84	17.26	12.35.
48	Iowa 2	Hamilton	B.	1.46	5.20	4.84	60.36	11.15	16.99
49	Ill. 7B	Collinsville	B.	1.03	4.69	5.14	60.71	14.77	13.66
50	Wash. 1B	Renton	S.	1.29	.80	5.16	63.35	16.82	12.58
51	Ind. 1	Mildred	B.	1.22	2.58	5.20	62.20	14.99	13.81

TABLE A—*Continued*

Proximate Analysis								
11	12	13	14	15	16	17	18	19
Moisture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
6.80	38.16	36.82	1.78	5863	10553	Carbonif.	Coal Meas.	Slack
1.26	48.97	21.24	1.81	5836	10505	Carbonif.	Pottsville	Slack
2.17	40.95	34.06	1.81	5853	10535	Carbonif.	Coal Meas.	Nut coal
4.14	43.75	32.64	1.85	6029	10852	Cretaceous	Mesaverde	Small mine
5.39	46.03	32.66	1.87	6020	10836	Cretaceous	Eagle	Mine; c. s.
0.52	58.60	12.11	1.90	6002	10804	Carbonif.	Pottsville	Bony layer
9.05	43.03	36.70	1.93	5989	10780	Tertiary	Fort Union	Mine; c. s.
6.76	44.45	33.71	1.93	6089	10960	Cretaceous	Mesaverde	Mine sam.
13.49	43.03	37.11	1.95	5995	10791	Cretaceous	Laramie	Mine; c. s.
4.92	43.89	33.68	1.95	6068	10922	Carbonif.	Coal Meas.	Screening
8.86	43.13	37.87	1.96	5994	10789	Cretaceous	Mesaverde	Little depth
4.38	44.73	30.90	1.96	6089	10960	Carbonif.	Coal Meas.	Screening
1.11	57.64	15.35	1.97	6967	10921	Carbonif.	Coal Meas.	Slack
9.22	44.52	32.71	1.98	6105	10989	Carbonif.	Coal Meas.	R. of M.
5.63	47.15	33.40	2.00	6126	11027	Cretaceous	Eagle	Mine; c. s.
6.67	42.02	36.01	2.01	6132	11043	Carbonif.	Coal Meas.	R. of M.
11.40	44.30	32.45	2.03	6106	10991	Carbonif.	Coal Meas.	Lump
9.02	47.55	36.59	2.04	a6039	10870	Cretaceous	Montana	Coal drift
10.12	48.13	35.70	2.04	b6040	10872	(?)	Up.Laramie	Exposed
5.12	42.92	34.88	2.04	6090	10962	Carbonif.	Coal Meas.	Small size
9.21	42.04	45.27	2.04	6116	11009	Tertiary	Fort Union	Mine; c. s
9.21	41.78	35.31	2.06	6110	10998	Carbonif.	Coal Meas.	
3.50	40.77	35.35	2.08	6191	11145	Carbonif.	Coal Meas.	
15.13	47.46	32.68	2.09	6199	11158	Carbonif.	Coal Meas.	R. of M.
10.78	43.94	40.46	2.10	a6057	10901	Cretaceous	Montana	Prospect
1.93	51.44	26.81	2.11	6094	10969	Cretaceous	Kootenai	Countryb'k
2.86	43.14	36.04	2.11	6180	11124	Carbonif.	Coal Meas.	Lump
5.98	45.96	35.15	2.12	6182	11128	Eocene		Pea coal c.s.
7.05	47.60	35.40	2.12	6226	11207	Cretaceous	Mesaverde	Mine sam.
8.52	46.95	32.18	2.12	6278	11300	Carbonif.	Coal Meas.	
4.25	41.75	37.02	2.14	6212	11182	Carbonif.	Coal Meas.	R. of M.
7.60	41.19	37.55	2.14	6229	11212	Carbonif.	Coal Meas.	
5.20	45.68	36.54	2.15	6273	11291	Eocene		Mine; c. s
8.66	42.67	39.86	2.16	6336	11405	Carbonif.	Coal Meas.	

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
51a	Philip	Batan Island	S.	1.33	1.36	5.55	62.91	23.39	5.56
52	Iowa 4	Centerville	B.	.94	4.46	5.31	61.25	16.56	11.48
52a	N. Mex. 3952	Nr. Blackrock	B.	1.03	1.54	5.45	63.00	12.36	16.62
52b	Wyo. 2325	Almy	S.	1.23	.22	4.97	64.28	21.56	7.73
52c	Colo. 3463	Lay	B.	1.16	1.05	5.50	63.43	22.37	6.49
53	Ill. 25B	Germantown	B.	1.12	5.06	5.05	60.96	13.57	14.24
53a	Wyo. 3917	Nr. Ft. Steele	S.	1.56	.85	5.16	63.57	25.05	3.80
54	Ill. 9C	Staunton	B.	.95	4.39	4.31	62.23	10.41	17.71
55	Ill. 22A	Maryville	B.	1.06	5.68	4.83	60.94	13.66	13.83
55a	Wyo. 3698	Labarge Range	S.	1.08	.84	5.68	63.81	25.75	2.84
56	Wyo. 4B	Hanna	S.	.88	.27	6.18	64.01	21.62	7.04
57	Ill. 29B	Livingston	B.	.85	4.68	5.11	61.69	14.62	13.05
57a	Wyo. 3605	Hanna	S.	1.29	.50	5.41	64.07	21.58	7.14
58	Ill. 6B	Coffeen	B.	1.10	4.67	4.69	61.96	12.15	15.43
59	Ill. 29	Livingston	B.	1.08	4.71	4.92	61.67	14.07	13.55
60	Iowa 1	Laddsdale	B.	.97	5.20	4.61	61.80	10.90	16.52
61	Ill. 1	O'Fallon	B.	1.07	4.25	5.09	62.01	13.86	13.72
62	Ill. 15	Centralia	B.	1.09	4.04	4.99	62.25	13.82	13.81
62a	Utah 4013	Nr. Sunnyside	B.	1.30	.47	4.71	64.88	20.11	8.53
63	Iowa 3	Altoona	B.	.93	6.83	4.93	60.62	11.16	15.53
64	N. Mex. 1	Gallup	S.	1.05	.64	5.73	64.34	21.14	7.10
65	Kans. 2B	Yale	B.	1.11	5.03	4.26	62.65	5.13	21.82
66	Ind. 14	Seelyville	B.	.97	5.34	4.99	62.05	11.90	14.75
66a	Colo. 3498	Meeker	B.	1.26	.76	5.20	64.95	20.41	7.42
67	Ind. 13	Terre Haute	B.	.87	3.37	5.25	63.39	14.31	12.81
68	Ind. 4	Star City	B.	1.24	2.59	4.66	64.10	11.36	16.05
69	Ill. 30	Shiloh Station	B.	1.03	4.80	4.92	62.60	12.20	14.45
70	Ill. 21	Troy	B.	1.22	1.55	4.94	64.76	15.34	12.20
71	Ill. 22B	Maryville	B.	1.00	4.90	4.52	62.99	10.23	16.36
72	Ind. T. 4	Lehigh	B.	1.38	4.02	4.84	63.21	13.15	13.40
72a	Colo. 3545	Book Cliffs Dis.	B.	1.47	0.66	5.58	65.05	20.96	6.28
73	Ill. 31	Worden	B.	1.14	4.05	4.83	63.47	11.84	14.67
73a	Colo. 3490	Book Cliffs field	B.	1.13	.89	5.13	65.51	16.92	10.42
73b	Mont. 4115	Stockett Dis.	B.	.92	2.43	4.33	65.17	12.66	14.49

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
7.06	43.44	43.94	2.17	c6101	10982	Miocene?		Prob. oxyd.
10.03	41.22	37.27	2.18	6237	11227	Carbonif.	Coal Meas.	Lump
4.01	40.22	39.12	2.18	6500	11700	Cretaceous	Mancos	Mine sam.
7.73	44.52	39.45	2.19	6220	11196	Tert-Cret.?	Evanston	Mine
9.87	46.97	36.67	2.19	6198	11156	Cretaceous	Mesaverde	Prospect
5.79	43.18	37.79	2.19	6337	11407	Carbonif.	Coal Meas.	Lump
8.70	48.44	39.05	2.20	6310	11358	Cretaceous	Lewis	Shaft
2.25	47.09	32.95	2.21	6273	11291	Carbonif.	Coal Meas.	
6.39	41.89	37.89	2.21	6267	11281	Carbonif.	Coal Meas.	Lump
10.22	45.98	39.47	2.23	a6258	11264	Cretaceous	Montana	Drift
8.94	42.70	41.32	2.23	6183	11129	Tertiary	Fort Union	Mine; c. s
7.14	44.09	35.72	2.23	6302	11344	Carbonif.	Coal Meas.	R. of M.
8.07	42.85	41.93	2.23	6420	11556	Tertiary	Fort Union	T.b.#1m.s.
4.17	47.77	32.63	2.24	6229	11212	Carbonif.	Coal Meas.	R. of M.
5.58	45.14	35.73	2.24	6393	11507	Carbonif.	Coal Meas.	
5.21	46.51	31.76	2.25	6329	11392	Carbonif.	Coal Meas.	Lump
6.28	41.08	38.92	2.25	6360	11448	Carbonif.	Coal Meas.	Screened
6.00	43.91	36.28	2.25	6356	11441	Carbonif.	Coal Meas.	Coarse coal
5.12	53.21	33.14	2.26	6293	11327	Cretaceous	Mesaverde	From Pros.
4.52	38.99	40.96	2.27	6309	11356	Carbonif.	Coal Meas.	Lump
10.86	46.90	35.14	2.28	6353	11435	Cretaceous	Mesaverde	Mine; c. s
1.51	48.42	28.25	2.32	6329	11392	Carbonif.	Coal Meas.	R. of M.
4.34	42.64	38.27	2.33	6430	11574	Carbonif.	Coal Meas.	R. of M.
7.18	46.50	38.90	2.33	6446	11603	Cretaceous	Mesaverde	Mine sam.
7.62	42.02	37.55	2.34	6414	11546	Carbonif.	Coal Meas.	R. of M.
3.58	47.41	32.96	2.34	6426	11632	Carbonif.	Coal Meas.	Sampled
3.27	43.18	39.10	2.35	6510	11718	Carbonif.	Coal Meas.	Coal # 6
5.74	47.17	34.89	2.35	6514	11725	Carbonif.	Coal Meas.	Lump
2.06	44.81	36.77	2.36	6376	11477	Carbonif.	Coal Meas.	Screenings
4.91	43.90	37.79	2.38	6327	11389	Carbonif.	Coal Meas.	Lump
10.00	50.98	32.74	2.38	b6312	11362	Cretaceous	Mesaverde	Prospect
3.77	45.94	35.62	2.39	6394	11509	Carbonif.	Coal Meas.	Screenings
6.17	47.13	36.28	2.39	6532	11758	Cretaceous	Mesaverde	Mine sam.
3.70	52.68	29.13	2.40	6348	11426	Cretaceous	Kootenai	Mine sam.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
73c	Wyo. 2283	Mammoth Holl	S.	1.03	.58	5.24	65.76	23.96	3.43
74	Ind. 2	Boonville	B.	1.25	4.60	5.11	62.97	12.56	13.51
75	Ind. 17	Bicknell	B.	.94	3.85	5.03	63.70	14.87	11.61
75a	Colo. 3462	Lay	B.	1.22	1.14	5.53	65.33	20.41	6.37
75b	Colo. 3704	Axial	B.	1.40	.54	5.24	66.12	21.92	4.78
76	Ill. 14	Springfield	B.	1.19	4.52	5.00	63.85	12.64	12.80
77	Ohio 3	Shawnee	B.	1.28	1.88	5.05	65.62	14.12	12.05
78	Ill. 12	Bush	B.	1.14	3.61	4.86	64.85	12.11	13.43
79	Kans. 2	Yale	B.	.94	6.40	4.56	63.14	6.69	18.27
80	Ind. 6	Hymera	B.	1.19	4.63	5.15	64.22	11.50	13.31
81	Ill. 9A	Staunton	B.	1.04	4.43	5.18	64.49	13.06	11.80
81a	Ariz. 4112	Nr. St. Michaels	B.	1.28	0.42	5.75	66.81	21.69	4.05
82	Ill. 26	Lincoln	B.	1.21	4.02	4.75	65.02	11.15	13.85
83	Wyo. 6	Kemmerer	S.	1.10	0.55	5.81	66.95	22.07	3.52
84	Ill. 19E	Ziegler	B.	1.53	0.54	4.54	67.48	14.99	10.92
84a	Colo. 3703	Axial	B.	1.12	0.60	5.20	67.42	22.64	3.02
85	Ala. 2B	Carbon Hill	B.	1.52	1.14	4.46	67.35	10.69	14.84
86	N. Mex. 3A	Van Houten	B.	1.25	0.74	4.83	67.54	8.63	17.01
87	Ind. 16	Linton	B.	1.13	4.50	5.02	64.82	12.04	12.49
88	Kans. 6	Jewett	B.	1.14	4.00	4.54	65.65	7.75	16.92
89	Tenn. 9B	Coalmont	B.	1.26	0.78	4.72	67.76	6.01	19.47
90	Mo. 5	Higbee	B.	1.02	5.68	4.69	64.52	8.72	14.37
91	Ind. 12	Hartwell	B.	1.25	4.13	5.01	65.28	11.88	12.45
92	Ohio 2	Superior	B.	1.25	4.17	5.17	65.14	12.51	11.76
93	N. Mex. 3B	Van Houten	B.	1.22	0.86	4.60	68.00	8.91	16.41
94	Ill. 23B	Donkville	B.	1.03	4.98	4.91	65.10	10.95	13.03
95	Ill. 19C	Ziegler	B.	1.49	0.54	5.10	67.19	13.53	11.43
96	Ill. 24A	New Baden	B.	1.10	5.33	4.94	64.86	12.20	11.57
97	Ill. 3	Marion	B.	1.43	1.77	4.92	67.30	12.99	11.59
98	Ind. 5	Hymera	B.	1.16	4.60	5.07	65.44	12.01	11.72
99	Ill. 9B	Staunton	B.	1.09	4.40	5.14	65.57	12.32	11.48
100	N. Mex. 3C	Van Houten	B.	1.20	0.65	4.75	68.66	9.00	15.74
101	Ind. 11	Dugger	B.	1.44	1.47	5.22	67.63	15.76	8.48
101a	Colo. 3550	B. Cliffs field	B.	1.26	0.63	5.19	68.46	13.25	11.21

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C — O+ash	Calories	B.T.U.	Age	Formation	Remarks
7.57	47.20	40.49	2.40	6385	11493	Cretaceous	Montana	Mine; shal.
6.24	42.76	37.49	2.41	6410	11538	Carbonif.	Coal Meas.	R. of M.
7.36	46.80	34.23	2.41	6446	11603	Carbonif.	Coal Meas.	R. of M.
8.66	47.29	37.68	2.44	b6419	11554	Cretaceous	Mesaverde	Outcrop
8.91	49.22	37.09	2.48	6534	11761	Cretaceous	Mesaverde	Mine sam.
5.13	44.31	37.70	2.50	6496	11693	Carbonif.	Coal Meas.	Lump
6.24	46.68	35.03	2.51	6519	11734	Carbonif.	Coal Meas.	Sample
4.77	48.34	33.46	2.54	6548	12786	Carbonif.	Coal Meas.	R. of M.
2.23	47.63	31.87	2.54	6600	11880	Carbonif.	Coal Meas.	R. of M.
5.91	42.71	38.07	2.58	6555	11799	Carbonif.	Coal Meas.	R. of M.
4.99	43.99	39.22	2.59	6538	11768	Carbonif.	Coal Meas.	R. of M.
9.89	46.95	39.07	2.59	6723	12101	Cretaceous	Mesaverde	
3.41	45.62	37.12	2.60	6579	11842	Carbonif.	Coal Meas.	R. of M.
8.68	46.49	41.31	2.61	d6456	11621	Cretaceous	Montana	R.of M.;c.s.
5.27	52.58	31.23	2.61	6625	11925	Carbonif.	Coal Meas.	Screened
8.67	49.99	38.32	2.62	6654	11977	Cretaceous	Mesaverde	O. D. sam.
2.29	51.64	31.23	2.63	6660	11988	Carbonif.	Pottsville	R. of M.
1.48	48.80	32.71	2.63	6742	12134	Cretaceous	Montana	Mine
4.68	44.24	38.59	2.64	6623	11921	Carbonif.	Coal Meas.	R. of M.
2.09	49.03	31.96	2.66	6663	11993	Carbonif.	Coal Meas.	Lump
1.03	52.89	26.61	2.66	6693	12047	Carbonif.	Pottsville	Slack
1.71	44.95	37.97	2.67	6614	11905	Carbonif.	Coal Meas.	R. of M.
4.45	45.68	37.42	2.68	6688	12038	Carbonif.	Coal Meas.	R. of M.
5.61	45.44	37.19	2.68	6625	11925	Carbonif.	Coal Meas.	R. of M.
1.40	48.98	33.21	2.68	6823	12281	Cretaceous	Montana	Mine
2.23	45.93	38.81	2.71	6598	11876	Carbonif.	Coal Meas.	Slack
6.01	52.23	30.33	2.72	6595	11873	Carbonif.	Coal Meas.	R. of M.
4.36	47.43	36.64	2.72	6575	11835	Carbonif.	Coal Meas.	Screenings
5.96	52.16	30.29	2.74	6724	12103	Carbonif.	Coal Meas.	R. of M.# 6
5.21	44.65	38.42	2.75	6700	12060	Carbonif.	Coal Meas.	R. of M.
4.03	44.18	40.31	2.75	6717	12090	Carbonif.	Coal Meas.	Lump
1.37	49.23	33.66	2.77	6855	12339	Cretaceous	Montana	Mine
8.49	48.16	34.87	2.79	6806	12251	Carbonif.	Coal Meas.	Lump
4.30	47.53	33.32	2.79	6757	12163	Cretaceous	Mesaverde	Mine sam.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
102	Ind. 9	Maxville	B.	1.12	3.56	5.19	66.48	12.46	11.20
103	Ind. 18B	Winston	B.	1.18	1.49	5.50	67.95	16.80	7.08
104	Ill. 34B	Harrisburg	B.	1.38	2.96	4.69	67.29	10.95	12.73
105	Ohio 1	Wellston	B.	1.17	4.85	5.12	65.70	10.59	12.57
106	Ill. 19	Ziegler	B.	1.48	0.57	4.85	69.05	14.23	9.82
107	Ind. 9B	Maxville	B.	1.19	3.53	5.14	66.79	11.30	12.05
108	Ky. 4	Wheatcroft	B.	1.28	4.67	4.53	66.50	8.43	14.59
109	Ohio 9B	Clarion	B.	1.12	3.55	4.80	67.31	10.58	12.64
110	Ill. 10	W. Frankford	B.	1.46	1.56	4.88	68.56	11.25	12.29
110a	Wyo. 3891	McDougals Mt.	B.	1.38	0.33	5.31	69.07	18.99	4.92
111	Ky. 3	Barnsley	B.	1.43	3.60	5.27	66.75	12.66	10.29
112	Ill. 12B	Bush	B.	1.02	2.60	4.80	68.30	11.74	11.54
112a	Wyo. 3509	Ft. Steele	B.	1.79	0.88	5.17	68.93	17.24	5.99
113	Mo. 6	Huntsville	B.	1.08	6.34	4.74	65.71	8.85	13.28
114	Ala. 2	Carbon Hill	B.	1.55	1.02	4.79	69.24	10.87	12.53
115	Ind. T. 8	(?)	B.	1.64	1.93	4.67	68.65	8.86	14.25
116	Ill. 12C	Bush	B.	1.19	2.65	4.83	68.36	11.02	11.95
117	Ind. 8	Terre Haute	B.	1.13	3.90	5.21	67.17	11.47	11.12
118	N. Mex. 4B	Brilliant	B.	1.53	0.62	4.97	69.48	8.62	14.78
119	Ill. 11B	Carterville	B.	1.37	2.62	4.88	68.25	10.50	12.38
120	Ill. 18	La Salle	B.	1.09	4.28	5.37	66.91	12.61	9.74
121	Ala. 5	Lehigh	B.	1.33	1.46	4.40	69.64	6.35	16.82
122	Ill. 13	Benton	B.	1.55	1.62	4.90	69.00	11.94	10.99
123	Ark. 1B	Huntington	Sb.	1.46	1.14	3.86	70.25	4.03	19.26
124	Ill. 28C	Herrin	B.	1.25	1.36	4.88	69.54	12.68	10.29
125	Ind. T. 2B	Hartshorne	B.	1.72	1.88	4.51	69.15	7.71	15.03
126	N. Mex. 4A	Brilliant	B.	1.53	0.62	5.03	69.86	9.19	13.77
127	Ill. 12D	Bush	B.	1.22	2.70	4.75	68.81	11.54	10.98
128	Wash. 2	Roslyn	B.	1.26	.38	5.08	70.26	10.60	12.42
129	Ky. 7	Central City	B.	1.32	2.71	5.06	67.80	12.34	9.77
130	Ky. 2	Earlington	B.	1.25	3.72	5.33	67.64	12.68	9.38
131	Ohio 11	Flushing	B.	1.19	4.39	4.71	67.72	8.84	13.15
132	Ind. 18A	Winslow	B.	1.38	1.69	5.48	69.08	15.17	7.20
133	Ky. 9A	McHenery	B.	1.24	3.25	5.41	68.01	12.80	9.29

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
5.24	45.73	37.83	2.81	6714	12085	Carbonif.	Coal Meas.	Lump
8.92	48.57	35.43	2.84	6881	12386	Carbonif.	Coal Meas.	Lump
2.92	51.25	33.10	2.84	6883	12389	Carbonif.	Coal Meas.	R. of M.
2.96	44.18	40.29	2.84	6727	12109	Carbonif.	Coal Meas.	R. of M.
6.39	54.46	29.33	2.86	6697	12055	Carbonif.	Coal Meas.	Sized coal
3.17	45.81	38.97	2.86	6811	12260	Carbonif.	Coal Meas.	R. of M.
2.54	46.78	36.08	2.88	6830	12294	Carbonif.	Coal Meas.	R. of M.
2.65	45.65	39.06	2.89	6805	12249	Carbonif.		Slack
2.79	50.57	34.35	2.89	6866	12359	Carbonif.		Slack
6.50	48.42	39.95	2.89	6879	12382	Cretaceous	Benton	Pros.; new
5.85	46.96	36.90	2.92	6829	12292	Carbonif.	Coal Meas.	R. of M.
3.97	51.43	36.06	2.93	6756	12161	Carbonif.	Coal Meas.	R. of M.
5.72	49.76	38.53	2.96	6759	12166	Cretaceous	Mesaverde	Mine
2.49	45.44	38.79	2.96	6785	12213	Carbonif.	Coal Meas.	Lump
2.58	51.74	33.15	2.96	6916	12449	Carbonif.	Pottsville	Sized
2.29	50.21	33.25	2.97	6837	12307	Carbonif.	Coal Meas.	Car sam.
3.32	51.70	33.03	2.97	6862	12352	Carbonif.	Coal Meas.	R. of M.
5.19	45.76	37.93	2.97	6848	12327	Carbonif.	Coal Meas.	Lump; d.c
1.40	49.02	34.80	2.97	6927	12469	Cretaceous	Montana	Screenings
3.25	51.19	33.18	2.99	6901	12422	Carbonif.	Coal Meas.	Mixed
4.36	45.63	40.27	2.99	6914	12445	Carbonif.	Coal Meas.	Lump
1.24	55.74	26.20	3.00	6920	12456	Carbonif.	Pottsville	R. of M.
3.89	51.94	33.18	3.00	6829	12292	Carbonif.	Coal Meas.	Egg coal
.85	63.64	16.25	3.01	6770	12186	Carbonif.	Coal Meas.	Slack
4.93	54.11	30.77	3.02	6849	12328	Carbonif.	Coal Meas.	Lump
1.44	49.49	34.04	3.04	6915	12447	Carbonif.	Coal Meas.	Slack
1.71	49.25	35.23	3.04	7034	12661	Cretaceous	Montana	Mine
2.97	53.54	32.51	3.05	6910	12438	Carbonif.	Coal Meas.	
1.88	48.73	36.97	3.05	7084	12715	Eocene		
5.64	48.26	36.33	3.06	6863	12353	Carbonif.	Coal Meas.	Lump
5.36	46.27	38.99	3.06	6966	12539	Carbonif.	Coal Meas.	Coarse coal
1.87	48.35	36.63	3.08	6937	12487	Carbonif.	Coal Meas.	Lump
8.29	48.28	36.23	3.08	6898	12416	Carbonif.	Coal Meas.	Slack
5.39	49.05	36.27	3.08	6953	12515	Carbonif.	Coal Meas.	Nut

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
134	Ala. 3	Garnsey	B.	1.15	.56	4.47	70.84	8.45	14.53
134a	Colo. 3541	Book Cliffs field	B.	1.58	.87	5.14	69.83	16.47	6.11
135	Ky. 9B	McHenery	B.	1.39	3.10	5.07	68.35	11.59	10.50
135a	Ill. 19B	Ziegler	B.	1.56	.64	4.51	70.55	13.11	9.63
136	Ind. 15	Linton	B.	1.56	1.00	5.11	69.89	13.47	8.97
136a	Colo. 3640	Book Cliffs field	B.	1.20	.49	5.38	70.52	16.87	5.74
137	Ind. T. 3	Edwards	B.	1.50	3.67	4.85	68.18	10.52	11.28
138	Kans. 4	Atchison	B.	1.07	8.33	5.04	65.02	7.91	12.63
139	Ill. 16	Herrin	B.	1.56	1.19	4.94	70.14	12.17	10.00
140	Va. 5A	Blacksburg	Sa.	.69	.66	3.60	72.23	4.02	18.80
141	N. Mex. 5	Blossburg	B.	1.19	.70	4.79	70.95	7.59	14.78
142	Ind. 7	Littles	B.	1.25	3.88	5.40	67.99	11.93	9.55
143	Kans. 1	Fleming	B.	1.09	4.34	4.91	68.22	8.30	13.14
144	Wyo. 5	Rock Springs	S.	1.52	.86	5.37	70.30	18.32	3.63
145	Ill. 11	Carterville	B.	1.39	2.07	4.84	69.91	10.64	11.15
146	Ind. T. 1	Henryetta	B.	1.29	1.99	5.14	69.85	11.38	10.35
146a	Colo. 3946	Rifle Creek	B.	1.63	.71	5.32	70.39	16.47	5.48
146b	Colo. 3586	Book Cliffs field	B.	1.63	1.31	5.33	70.00	15.34	6.39
146c	Wyo. 4302	Willow Creek	B.	1.55	.64	4.65	71.09	15.74	6.33
147	Ill. 19B	Ziegler	B.	1.48	.96	4.96	70.70	11.98	9.92
147a	Colo. 3943	Rifle Creek	B.	1.60	1.14	5.36	70.20	15.63	6.07
147b	Cal. 3773	Stone Canyon	B.	1.19	4.26	6.18	67.50	14.50	6.37
148	Ohio 7	Danford	B.	1.23	3.21	5.14	69.19	10.40	10.83
149	Ind. 7B	Littles	B.	1.24	4.14	5.11	68.94	10.34	10.23
149a	Colo. 3546	Book Cliffs field	B.	1.60	.74	5.38	71.03	15.16	6.09
150	Tenn. 6	Waldencia	B.	1.01	.80	4.66	72.14	6.53	14.86
151	Tenn. 9A	Coalmont	B.	1.32	.96	4.64	71.84	6.78	14.46
152	R. I. 1	Providence	G.	.17	.07	.69	76.63	2.99	19.45
153	Ind. 10	Rosedale	B.	1.26	4.17	5.40	69.07	10.77	9.33
154	Ohio 8	Dixie	B.	1.35	2.97	5.21	70.18	11.52	8.76
154a	Wyo. 3480	Ft. Steele	B.	1.79	.95	5.56	71.24	16.73	3.71
155	Tenn. 1	Fork Ridge	B.	1.65	1.63	4.95	71.36	8.92	11.49
156	Pa. 13	Creighton	B.	1.23	2.19	5.02	71.25	6.96	13.35
157	Tenn. 1	Clifty	B.	1.25	4.84	4.55	69.59	5.36	14.41

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C / O+ash	Calories	B.T.U.	Age	Formation	Remarks
1.54	54.11	29.82	3.08	7007	12523	Carbonif.	Pottsville	R. of M.
5.63	51.49	36.77	3.09	6978	12470	Cretaceous	Mesaverde	Mine sam.
3.91	51.49	34.10	3.09	6985	12483	Carbonif.	Coal Meas.	R. of M.
3.87	55.19	31.31	3.10	6897	12325	Carbonif.	Coal Meas.	Lump # 6
4.93	50.82	35.28	3.11	6979	12467	Carbonif.	Coal Meas.	R. of M.
5.21	55.69	33.36	3.11	6908	12344	Cretaceous	Pocono	Shallow; m.
3.45	47.82	37.45	3.12	6927	12379	Carbonif.	Montana	R. of M.
3.57	46.80	37.00	3.16	6854	12247	Carbonif.	Coal Meas.	Lump
4.61	54.05	31.35	3.16	6921	12368	Carbonif.	Coal Meas.	Lump
.73	69.92	10.55	3.16	6929	12382	Carbonif.	Montana	
1.34	51.58	32.30	3.17	7065	12627	Cretaceous	Coal Meas.	Mine
5.50	44.99	39.96	3.17	6920	12334	Carbonif.	Coal Meas.	Lump
3.74	50.01	33.11	3.18	6891	12314	Carbonif.	Coal Meas.	
6.00	51.68	38.69	3.20	6955	12429	Cretaceous	Montana	Mine c. s.
3.11	52.71	33.03	3.21	6978	12470	Carbonif.	Coal Meas.	
3.87	50.05	35.73	3.21	7011	12531	Carbonif.	Coal Meas.	
4.24	53.04	37.24	3.21	7075	12646	Cretaceous	Mesaverde	Mine sam.
4.84	50.49	38.28	3.22	7024	12554	Cretaceous	Mesaverde	Prospect
4.51	54.85	34.20	3.22	6911	12351	Cretaceous	Benton	Prospect
5.42	53.03	31.63	3.23	6877	12290	Carbonif.	Coal Meas.	Lump
4.31	51.93	37.68	3.23	7072	12641	Cretaceous	Mesaverde	Mine sam.
4.86	41.03	47.74	3.24	7086	12666	Miocene		Mine sam.
4.16	50.17	34.84	3.26	6947	12416	Carbonif.	Coal Meas.	
2.76	46.55	40.46	3.34	7020	12548	Carbonif.	Coal Meas.	Screenings
5.49	54.10	34.32	3.34	7069	12636	Cretaceous	Mesaverde	Deep Pros.
1.02	55.69	28.43	3.37	7159	12798	Carbonif.	Pottsville	R. of M.
1.36	56.22	27.96	3.38	7135	12755	Carbonif.	Pottsville	Lump
.42	75.11	5.02	3.41	6229	11212	Carbonif.	Coal Meas.	Not a fuel
2.85	45.07	42.75	3.43	7113	12803	Carbonif.	Coal Meas.	Lump
3.19	48.26	39.79	3.46	7055	12699	Carbonif.	Coal Meas.	R. of M.
5.45	52.89	37.95	3.48	a6951	12512	Cretaceous	Mesaverde	W. in mine
1.87	52.71	33.93	3.48	7199	12958	Carbonif.	Pottsville	R. of M.
1.27	51.89	33.49	3.50	7221	13098	Carbonif.	Coal Meas.	R. of M.
1.14	50.87	33.58	3.52	7096	12873	Carbonif.	Pottsville	R. of M.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
158	Tenn. 7A	Wilder	B.	1.29	3.32	4.92	70.46	6.94	13.07
159	Ala. 1	Horse Creek	B.	1.66	.73	4.96	72.16	7.85	12.64
160	Ind. T. 2	Hartshorne	B.	1.72	1.56	5.00	71.49	8.91	11.32
160a	Colo. 3936	Newcastle	B.	1.40	.44	5.07	72.65	13.49	6.95
161	Ga. 1	Menlo	Sb.	1.13	1.31	4.09	72.92	5.58	14.97
161a	Wyo. 4323	Greys	B.	1.48	.28	5.14	72.97	18.45	1.68
162	Va. 5B	Blacksburg	Sa.	.74	.70	3.85	74.33	2.91	17.47
163	Pa. 3	Scranton	A.	.80	.77	2.81	75.21	4.08	16.33
164	Tenn. 8A	Clifty	B.	1.17	4.45	4.97	70.45	5.50	13.64
165	Ill. 34A	Harrisburg	B.	1.53	2.51	4.96	71.55	10.55	8.90
166	Ala. 4	Belle Ellen	B.	1.25	1.14	4.89	73.09	5.96	13.67
166a	Colo. 3587	Book Cliffs field	B.	1.65	1.08	5.64	72.46	13.12	6.05
167	Ohio 12B	Bellaire	B.	1.25	3.70	5.07	71.13	8.75	10.10
168	Ohio 10	Mineral City	B.	1.32	3.00	5.55	71.28	11.14	7.71
169	Pa. 6	E. Millsboro	B.	1.27	1.88	4.67	72.87	6.43	12.87
170	Ill. 11C	Carterville	B.	1.43	1.76	4.99	72.80	10.84	8.18
171	Ohio 9A	Clarion B.	B.	1.22	3.25	4.67	72.07	10.23	8.56
171a	Colo. 3938	Newcastle	B.	1.76	.54	5.05	73.45	14.22	4.98
171b	Colo. 3585	Book Cliffs field	B.	1.63	1.37	5.52	72.62	13.53	5.33
171c	Colo. 3932	Newcastle	B.	1.45	.42	5.21	73.98	13.53	5.41
172	Ohio 12A	Bellaire	B.	1.23	4.07	5.03	71.44	8.60	9.63
173	Kans. 5	Westminster	B.	1.09	3.86	4.96	71.90	7.40	10.79
173a	Wyo. 3570	Oyster Ridge	B.	1.18	.48	5.10	74.41	14.36	4.47
173b	Colo. 3939	Newcastle	B.	1.73	.52	5.17	73.87	13.62	5.09
174	Tenn. 4	Oliver Springs	B.	1.63	1.03	5.13	73.62	8.58	10.00
174a	Colo. 4036	N. of Sunlight	B.	1.78	.53	5.49	73.65	16.61	1.94
175	W. Va. 22B	Hernshaw	B.	1.18	1.04	5.06	74.16	8.47	10.09
175a	Colo. 4225	Nr. Mancos	B.	1.50	1.03	5.69	73.73	12.18	5.87
176	Pa. 17	White	B.	1.44	1.56	4.83	74.06	5.80	12.31
176a	Colo. 7573	Hesperus	B.	1.40	.66	5.32	74.41	12.39	5.82
177	W. Va. 25	Spring Hill	B.	1.43	.66	5.02	74.61	10.89	7.39
178	Ohio 4	Crow Hollow	B.	1.33	3.52	5.06	72.68	8.16	9.25
179	Ark. 8	Spadra	Sa.	.53	2.14	3.44	75.77	3.47	14.65
179a	Colo. 4048	Sunlight	B.	1.86	.96	5.36	74.10	14.72	3.00

TABLE A—*Continued*

Proximate Analysis								
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
1.36	50.06	35.51	3.52	7122	12921	Carbonif.	Pottsville	Lump
1.56	53.71	32.10	3.52	7199	13059	Carbonif.	Pottsville	Sized
1.70	49.79	37.19	3.53	7205	13070	Carbonif.	Coal Meas.	R. of M.
2.81	53.45	36.99	3.55	7243	13138	Cretaceous	Mesaverde	Mine sam.
.62	68.01	16.40	3.55	7341	13315	Carbonif.	Pottsville	Lump
4.20	56.36	37.60	3.62	7358	13345	Crétaceous	Benton	Prospect
.45	71.00	11.08	3.65	7112	12903	Carbonif.	Pocono	
2.08	74.32	7.27	3.68	6929	12573	Carbonif.	Coal Meas.	Waste culm
1.05	51.26	34.05	3.68	7179	13023	Carbonif.	Pottsville	Lump
2.13	53.36	35.61	3.68	7324	13284	Carbonif.	Coal Meas.	Screenings
.98	55.13	30.22	3.72	7287	13218	Carbonif.	Pottsville	R. of M.
4.17	52.20	37.58	3.77	a7207	13074	Cretaceous	Mesaverde	Countryb'k
1.69	50.10	38.11	3.77	7280	13206	Carbonif.	Coal Meas.	
2.24	48.55	41.50	3.78	7368	13364	Carbonif.	Coal Meas.	Lump
1.27	53.52	32.43	3.78	7301	13244	Carbonif.	Coal Meas.	R. of M.
2.36	54.84	34.62	3.82	7263	13175	Carbonif.	Coal Meas.	
2.47	50.89	38.08	3.83	7331	13298	Carbonif.	Coal Meas.	Lump
2.73	53.60	38.67	3.83	7429	13474	Cretaceous	Mesaverde	Mine sam.
4.78	52.69	39.20	3.85	7182	13030	Cretaceous	Mesaverde	Mine sam.
3.19	55.49	35.91	3.91	7364	13357	Cretaceous		Mine sam.
1.58	48.44	40.35	3.92	7443	13319	Carbonif.	Coal Meas.	R. of M.
1.84	54.97	32.40	3.95	7333	13201	Carbonif.	Coal Meas.	Screened
3.84	55.47	36.06	3.95	7336	13297	Cretaceous	Benton	Prospect
2.90	53.35	38.66	3.95	7441	13486	Cretaceous	Mesaverde	Mine sam.
1.77	54.32	33.91	3.96	7333	13201	Carbonif.	Pottsville	R. of M.
4.18	54.63	39.25	3.97	7465	13529	Cretaceous	Mesaverde	Mine sam.
1.74	53.80	34.37	3.99	7344	13311	Carbonif.	Pottsville	R. of M.
3.51	51.12	39.50	4.08	a7316	13261	Cretaceous	Mesaverde	Shallow m.
1.09	57.87	28.71	4.08	7448	13498	Carbonif.	Coal Meas.	R. of M.
3.33	53.77	37.08	4.08	7461	13522	Cretaceous	Mesaverde	Mine sam.
1.95	54.42	36.24	4.08	7608	13786	Carbonif.	Coal Meas.	Lump
2.16	50.61	37.98	4.17	7365	13349	Carbonif.	Coal Meas.	Screened
.83	73.55	10.97	4.18	7244	13131	Carbonif.	Coal Meas.	Stove coal
3.10	55.32	38.58	4.18	7564	13707	Cretaceous	Mesaverde	"D" bed

TABLE A—*Continued*

				Ultimate Analysis					
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
180	Ky. 8	Sturgis	B.	1.23	1.22	4.87	74.99	9.51	8.18
181	Ark. 12	(?)	Sb.	1.38	1.68	3.78	75.49	4.15	13.52
182	Ark. 1	Huntington	Sb.	1.47	1.27	4.00	75.68	4.70	12.88
183	Ohio 5	Rush Run	B.	1.45	1.76	5.06	74.44	9.81	7.48
184	Utah 1	Price	B.	1.43	.57	5.55	75.18	12.21	5.06
185	Tenn. 5	Petros	B.	1.69	3.38	4.97	73.23	6.53	10.20
186	Tenn. 3	Gatliff	B.	1.78	1.02	5.31	74.80	9.81	7.28
187	Ohio 6	Neffs	B.	1.17	3.47	5.16	73.58	7.76	8.87
188	Ind. T. 2C	Hartshorne	B.	1.88	1.25	5.03	74.50	8.87	8.87
189	Pa. 22	Huff	B.	1.58	1.03	4.77	75.69	6.44	10.49
190	Md. 1	Georges Creek	Sb.	1.32	1.51	3.88	76.28	3.69	13.32
191	Pa. 12	Acheson	B.	1.46	2.21	4.76	74.89	7.36	9.32
192	W. Va. 22A	Hernshaw	B.	1.22	.85	5.05	76.01	8.89	7.98
193	Pa. 7	Ligonier	B.	1.55	2.15	4.51	75.19	3.72	12.88
194	Tenn. 9C	Coalmont	B.	1.28	.67	4.83	76.37	7.27	9.58
195	Ark. 3	Jenny Lind	Sb.	1.55	1.30	4.07	76.37	4.91	11.80
196	Pa. 21	Connelsville	B.	1.57	.90	4.63	76.34	7.47	9.09
197	Pa. 4	Greensburg	B.	1.46	1.29	4.82	76.00	5.78	10.64
198	W. Va. 3	Richard	B.	1.44	1.07	4.91	76.12	6.09	10.37
199	W. Va. 23B	Monarch	B.	1.19	1.36	5.04	76.02	8.24	8.15
200	W. Va. 5	Coalton	B.	1.48	.99	4.78	76.36	6.21	10.18
201	W. Va. 16	Monongah	B.	1.53	1.26	4.80	76.09	7.56	8.76
202	Pa. 19	Herminie	B.	1.42	1.08	4.92	76.25	7.76	8.57
203	Mo. 4	Bernet	B.	.75	5.55	5.77	72.45	10.25	5.23
204	Ky. 1B	Straight Creek	B.	1.73	1.66	5.06	75.89	7.62	8.54
205	W. Va. 2	Clarksburg	B.	1.37	3.50	5.09	74.44	7.70	7.90
206	Ark. 7A	Midland	Sb.	1.32	2.12	3.99	76.37	3.91	12.29
207	Tenn. 2	Gatliff	B.	1.81	1.01	5.20	75.97	8.98	7.03
208	W. Va. 4B	Bretz	B.	1.60	1.10	4.52	76.72	5.68	10.38
208a	Wyo. 4303	Willow Creek	B.	1.31	.94	5.04	76.84	12.64	3.23
208b	Colo. 4010	Gulch	B.	1.56	.45	5.16	77.05	9.46	6.32
208c	Ala. 3499	Lovick	B.	1.69	1.10	4.89	76.64	7.20	8.48
209	W. Va. 23A	Monarch	B.	1.45	1.24	5.13	76.57	7.90	7.71
210	Va. 6	Richlands	B.	1.33	1.27	4.44	77.21	5.45	10.30

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
2.33	57.48	32.01	4.24	7598	13768	Carbonif.	Coal Meas.	R. of M.
1.22	68.58	16.68	4.27	7282	13200	Carbonif.	Coal Meas.	Slack
1.17	68.12	17.83	4.30	7450	13502	Carbonif.	Coal Meas.	S
1.99	54.13	36.40	4.31	7501	13594	Carbonif.	Coal Meas.	Screened
2.34	48.92	43.66	4.35	7595	13763	Cretaceous	Mesaverde	
1.35	53.32	35.13	4.37	7456	13513	Carbonif.	Pottsville	R. of M.
2.25	54.79	35.68	4.38	7489	13572	Carbonif.	Pottsville	R. of M.
1.47	51.45	38.21	4.42	7425	13456	Carbonif.	Coal Meas.	R. of M.
1.43	53.08	36.62	4.45	7505	13601	Carbonif.	Coal Meas.	Lump
.91	59.57	29.03	4.47	7632	13830	Carbonif.	Coal Meas.	R. of M.
.94	69.40	16.34	4.48	7469	13536	Carbonif.	Coal Meas.	
1.27	58.64	30.77	4.49	7621	13810	Carbonif.	Coal Meas.	R. of M.
1.45	56.40	37.17	4.50	7645	13853	Carbonif.	Pottsville	Screenings
.92	64.90	21.30	4.52	7549	13680	Carbonif.	Coal Meas.	R. of M.
1.43	59.26	29.73	4.54	7563	13705	Carbonif.	Pottsville	Slack
.80	67.65	19.75	4.57	7586	13747	Carbonif.	Coal Meas.	
.97	60.85	29.09	4.61	7751	14044	Carbonif.	Coal Meas.	R. of M.
.97	57.44	30.95	4.62	7616	13601	Carbonif.	Coal Meas.	Lump
1.00	58.38	30.25	4.62	7631	13828	Carbonif.	Coal Meas.	R. of M.
1.46	55.47	34.92	4.64	7661	13882	Carbonif.	Pottsville	Slack
.65	59.97	20.20	4.65	7682	13920	Carbonif.	Coal Meas.	Coarse coal
1.22	56.96	33.06	4.66	7609	13788	Carbonif.	Coal Meas.	Screenings
1.01	57.85	32.57	4.67	7752	14046	Carbonif.	Coal Meas.	R. of M.
5.39	44.47	44.91	4.68	7516	13621	Carbonif.	Coal Meas.	R. of M.
1.57	55.14	34.75	4.69	7623	13813	Carbonif.	Pottsville	
1.46	50.50	40.14	4.70	7700	13952	Carbonif.	Coal Meas.	R. of M.
.60	70.00	17.11	4.71	7413	13435	Carbonif.	Coal Meas.	Slack
1.95	54.05	36.97	4.74	7630	13828	Carbonif.	Pottsville	R. of M.
1.35	60.88	37.39	4.77	7626	13819	Carbonif.	Coal Meas.	R. of M.
1.99	57.53	37.18	4.84	7812	14154	Cretaceous	Benton	Prospect
1.21	57.30	35.17	4.88	7860	14240	Cretaceous	Mesaverde	Mine sam.
1.19	59.43	30.90	4.88	7613	13795	Carbonif.	Pottsville	
1.58	55.50	35.21	4.90	7643	13849	Carbonif.	Pottsville	R. of M.
.65	64.77	24.28	4.90	7757	14055	Carbonif.	Pottsville	R. of M.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
210a	Ala. 3745	Coalmont	B.	1.13	.88	5.01	77.40	8.28	6.30
211	Ark. 5	Coal Hill	Sa.	1.39	2.01	3.74	77.29	3.36	12.21
211a	Colo. 3552	Nr. Durango	B.	1.50	1.38	5.29	76.63	9.89	5.31
212	Pa. 9	Kimmelton	Sb.	1.29	2.09	4.00	77.42	3.58	11.63
213	W. Va. 11	Zenith	Sb.	1.04	.53	4.03	79.12	3.78	11.50
214	Pa. 11	Charleroi	B.	1.45	1.19	5.09	77.32	7.62	7.33
215	W. Va. 15	Clarksburg	B.	1.44	2.56	5.03	76.52	5.82	8.63
215a	Wyo. 4299	Willow Creek	B.	.85	.71	5.59	78.19	11.18	3.48
216	W. Va. 14	Bretz	B.	1.50	.90	4.85	78.21	6.11	8.43
216a	Ala. 3771	Acton Basin	B.	1.53	.44	5.15	78.67	8.46	5.75
217	Va. 4	Darby	B.	1.35	.81	5.13	78.56	9.73	4.42
218	Va. 2B	Crab Orchard	B.	1.45	.94	5.08	78.51	8.33	5.69
219	W. Va. 1	Kingmont	B.	1.55	.90	5.26	78.31	7.61	6.37
220	Pa. 10	Bruce	B.	1.59	1.28	5.14	78.16	7.58	6.25
221	Va. 1	Crab Orchard	B.	1.27	1.23	5.17	78.47	9.01	4.85
222	W. Va. 20	Acme	B.	1.37	1.41	5.04	78.39	5.59	8.20
223	W. Va. 8	Ansted	B.	1.38	.92	5.16	78.75	6.43	7.36
224	Ky. 6	Miller Creek	Sp.	1.48	.58	5.35	78.94	10.83	2.82
225	W. Va. 17	Nr. Bretz	B.	1.41	1.49	4.51	78.95	5.31	8.33
226	Pa. 5	Ellsworth	B.	1.55	.89	5.20	78.78	7.47	6.11
227	Pa. 16	Hastings	Sb.	1.33	1.65	4.46	79.00	5.37	8.19
227a	Ala. 3769	Acton Basin	B.	1.25	1.10	5.01	79.16	8.83	4.65
228	Pa. 20	Seward	Sb.	1.16	2.96	4.55	78.23	2.17	10.93
229	Ky. 1	Straight Creek	B.	1.85	1.24	5.36	78.31	8.80	4.44
230	Pa. 15B	Wehrum	Sb.	1.18	4.06	4.29	77.52	2.40	10.55
231	W. Va. 18	Glen Alum	B.	1.45	.68	4.91	79.65	7.39	5.92
231a	Ala. 3744	Fall Ston	Sb.	1.33	.67	5.26	79.50	10.03	3.21
231b	Colo. 4047	Coal Basin	B.	1.83	.52	4.65	79.77	4.59	8.64
232	W. Va. 9	Powellton	B.	1.63	.80	5.04	79.35	6.39	6.79
233	Ky. 5	Big Black Mtn.	B.	1.61	.69	4.99	79.67	9.23	3.81
234	W. Va. 21	Winifrede	B.I.	1.52	1.35	5.21	79.15	7.83	4.95
235	Ala. 6	Dolomite	B.	1.45	.63	4.84	80.25	5.94	6.88
236	Ark. 2	Bonanza	Sb.	1.40	1.90	4.13	80.03	3.20	9.34
237	Pa. 15	Wehrum	Sb.	1.17	3.88	4.43	78.61	1.82	10.09

TABLE A—*Continued*

Proximate Analysis

11	12	13	14	15	16	17	18	19
Moisture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
1.67	59.11	32.92	4.96	7764	14067	Carbonif.	Pottsville	Mine sam.
1.28	73.69	12.82	4.96	7443	13489	Carbonif.	Coal Meas.	
2.07	54.22	38.40	5.04	b7676	13909	Cretaceous	Mesaverde	Weathered
.50	70.12	17.75	5.09	7657	13875	Carbonif.	Coal Meas.	R. of M.
.80	70.80	16.90	5.17	7761	14062	Carbonif.	Pottsville	R.of M.Poca.
1.36	57.03	34.28	5.17	7699	13950	Carbonif.	Coal Meas.	R.of M.Pitts.
1.12	52.60	37.65	5.29	7743	14029	Carbonif.	Coal Meas.	R.of M.Pitts.
2.37	57.33	36.79	5.33	7713	13975	Cretaceous	Benton	Tunnel
.98	61.87	28.72	5.37	7855	14231	Carbonif.	Coal Meas.	R. of M.
1.86	58.75	33.64	5.53	7791	14116	Carbonif.	Pottsville	Helena
2.40	55.54	37.64	5.55	7902	14316	Carbonif.	Pottsville	Screened
1.48	57.02	35.81	5.59	7890	14294	Carbonif.	Pottsville	R. of M.
1.35	55.36	36.92	5.60	7869	14256	Carbonif.	Coal Meas.	R. of M.
1.33	57.04	35.38	5.64	7877	14271	Carbonif.	Coal Meas.	Nut
1.70	57.66	35.79	5.66	7870	14258	Carbonif.	Pottsville	R. of M.
.74	58.17	32.89	5.68	7812	14154	Carbonif.	Pottsville	R. of M.
1.60	58.92	32.12	5.71	7863	14245	Carbonif.	Pottsville	R. of M.
2.99	56.88	37.31	5.78	7807	14145	Carbonif.	Pottsville	Splint
1.00	62.68	27.99	5.78	7903	14317	Carbonif.	Coal Meas.	Prospect
1.47	57.59	34.83	5.80	7864	14247	Carbonif.	Coal Meas.	Sc'd Pitts.
.36	68.78	22.67	5.83	7812	14154	Carbonif.	Coal Meas.	R. of M.
1.62	59.87	33.86	5.87	7964	14427	Carbonif.	Pottsville	Helena coal
.42	72.17	16.48	5.90	7692	13938	Carbonif.	Coal Meas.	R. of M.
1.92	57.08	36.56	5.91	7955	14411	Carbonif.	Pottsville	R. of M.
.48	70.49	18.48	5.98	7781	14098	Carbonif.	Coal Meas.	R. of M.
1.28	59.03	33.77	5.98	7963	14425	Carbonif.	Pottsville	R. of M.
1.52	60.68	34.59	6.01	8115	14699	Carbonif.	Pottsville	Buck bed
.76	69.07	21.53	6.03	7977	14451	Cretaceous	Mesaverde	R. of M.
1.01	62.67	29.53	6.03	7984	14463	Carbonif.	Pottsville	R. of M.
1.60	58.56	36.03	6.10	7958	14416	Carbonif.	Pottsville	Split; Pros.
1.50	56.39	37.16	6.19	7915	14339	Carbonif.	Pottsville	R.ofM.;W.c.
.85	65.47	26.80	6.26	8011	14512	Carbonif.	Pottsville	R.of M. P.c.
.74	73.66	16.26	6.38	7756	14153	Carbonif.	Coal Meas.	R. of M.
.34	71.45	18.12	6.60	7885	14385	Carbonif.	Coal Meas.	R. of M.

TABLE A—*Continued*

				Ultimate Analysis					
1	2	3	4	5	6	7	8	9	10
No.	Designation of Coal	Locality	Kind	N.	S.	H.	C.	O.	Ash
238	Pa. 18	Lloydell	Sb.	1.23	1.55	4.53	80.74	3.02	8.83
239	W. Va. 14	Loup Creek	B.	1.56	1.06	5.15	80.73	8.12	2.38
239a	Ark. 3174	Paris	Sa.	1.49	2.85	3.87	80.48	2.04	9.27
239b	Pa. "L"	Johnstown	Sb.	1.27	2.29	4.04	81.10	2.99	8.31
240	W. Va. 7	Sun.	Sb.	1.05	1.20	4.38	82.41	5.87	5.09
241	Md. 2	Frostburg	Sb.	1.49	.86	4.54	82.39	3.43	7.29
242	Ind. T. 9	Panama Dis.	Sa.	1.68	1.24	4.35	82.06	2.26	8.41
242a	Ala. 3770	Sydenton	B.	1.55	.49	5.34	82.09	6.69	3.84
243	Va. 3	Coeburn	B.	1.63	.68	5.04	82.16	5.91	4.58
244	Pa. 8	Ehrenfield	Sb.	1.29	.97	4.37	83.11	3.43	6.83
245	W. Va. 13	Page	B.	1.36	.91	5.15	82.65	5.91	4.01
246	W. Va. 12A	Big Sandy	Sb.	1.34	.69	4.36	83.63	3.03	6.95
247	W. Va. 12	Big Sandy	Sb.	1.33	.85	5.06	83.18	3.36	6.22
248	W. Va. 6	Rush Run	Sb.	1.70	.66	4.70	83.62	4.23	5.09
249	W. Va. 19	McDonald	Sb.	1.60	.91	4.66	83.56	4.13	5.13
250	W. Va. 10	Mora	Sb.	1.07	.57	4.53	85.91	3.24	4.63

TABLE A—*Continued*

						Proximate Analysis		
11	12	13	14	15	16	17	18	19
Mois-ture	Fixed Carbon	Volatile Matter	C O+ash	Calories	B.T.U.	Age	Formation	Remarks
.38	74.69	16.10	6.81	7926	14459	Carbonif.	Coal Meas.	
2.05	64.57	30.00	7.01	8090	14754	Carbonif.	Pottsville	R. of M.
.59	75.12	15.02	7.11	7824	14375	Carbonif.	Coal Meas.	
.64	76.38	14.67	7.18	7934	14573	Carbonif.	Coal Meas.	L.Kitt'g c.
.76	73.61	20.54	7.52	8254	15249	Carbonif.	Pottsville	R. of M.S. c.
.74	73.83	18.14	7.68	8086	14947	Carbonif.	Coal Meas.	Pitts. coal
.64	76.66	14.29	7.69	7948	14698	Carbonif.	Coal Meas.	
1.28	60.32	34.56	7.79	8180	15116	Carbonif.	Pottsville	Wads'h coal
.87	62.19	32.36	7.83	8220	16288	Carbonif.	Pottsville	Screened
.63	75.22	17.32	8.10	8170	16198	Carbonif.	Coal Meas.	R. of M.
1.17	62.95	31.87	8.32	8234	16313	Carbonif.	Pottsville	R. of M.
.62	74.38	18.05	8.38	8185	16225	Carbonif.	Pottsville	R. of M.
1.93	.....	.....	8.68	8300	16433	Carbonif.	Pottsville	Briquettes
.64	72.53	21.74	8.97	8301	16435	Carbonif.	Pottsville	R. of M.
.68	70.91	23.28	9.01	8203	16258	Carbonif.	Pottsville	R. of M.,S.c.
.65	75.92	18.80	10.91	8439	16683	Carbonif.	Pottsville	Poca.; Pros.

ABBREVIATIONS USED IN THE TABLE

c. s.—Car Sample
d. c.—Deep coal
Kit'g.—Kittanning
Nr.—Near
O. D.—Old Drift
Pros.—Prospect
R. of M.—Run of Mine
Sam.—Sample
S. c.—Sewell Coal
Sc'd—Screened
Shal.—Shallow
Wads'h—Wadsworth
W.—Weathered

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